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STABILITY CHARACTERISTICS OF
A MANNED LIFTING ENTRY VEHICLE
WITH VARIOUS FINS AT
MACH NUMBERS FROM 1.50 TO 2.86

by H. Norman Silvers and James F. Campbell

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

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An investigation has been conducted in the Langley Unitary Plan wind tunnel and in the Langley 4- by 4-foot supersonic pressure tunnel to determine the effects of various fin arrangements on the stability characteristics, in particular the directional stability characteristics, of a manned lifting entry vehicle.

The results showed that increasing either the span or the chord of the tip fins provided directional stability. Increases in directional stability also resulted from increasing the chord of the center fin, attaching an end plate to the center fin, and fitting trailing-edge wedge sections to the center fin.

The canopy had a large destabilizing effect on the directional stability of the basic body.

INTRODUCTION

The National Aeronautics and Space Administration is engaged in a general research effort to determine the aerodynamic characteristics and problems associated with a manned lifting entry vehicle having a maximum hypersonic lift-drag ratio of about 1.0. The configuration evolved after an extensive review of configuration types and an analysis of hypersonic and low-subsonic results on some selected preliminary configurations (refs. 1 and 2). The vehicle shape selected for further study has been designated the basic HL-10 (horizontal lander 10).

The results reported in reference 3 indicated that low directional stability at the lower supersonic Mach numbers is a problem area of the basic HL-10. The present investigation was therefore made to provide information on the effectiveness of various arrangements of stabilizing surfaces in improving the directional stability characteristics. The results presented herein were

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obtained in the Langley Unitary Plan wind tunnel over an angle-of-attack range
that extended from low angles to 21° and 38° at Mach numbers of 1.50, 1.80,
and 2.16. Some directional stability characteristics were also obtained at
M = 2.86. In addition, results were obtained in the Langley 4- by 4-foot super-
sonic pressure tunnel over an angle-of-attack range from about -7° to 27° at a
Mach number of 2.21. The fins investigated in the Unitary Plan tunnel included
several long-span tip fins which were reduced systematically in span by
removing tip area, a tip fin designated D-1 in reference 3, and fin D-1 with a
rearward chord extension. The effects of attaching a canopy to the basic body
and reducing the span of the center fin were also determined in the Mach num-
ber range from 1.50 to 2.86.

The fins investigated at a Mach number of 2.21 were the tip fin of refer-
ence 3 (fin D-1) with two lengths of rearward chord extension and the center
fin of reference 3 (fin E) with a rearward chord extension. The extended-chord
center fin was also tested with and without a delta-shaped end plate attached
to the tip chord.

SYMBOLS

Measurements for this investigation were taken in the U.S. Customary
System of Units. Equivalent values are indicated herein parenthetically in the
International System (SI) in the interest of promoting use of this system in
future NASA reports. Details concerning the use of SI, together with physical
constants and conversion factors, are given in reference 4.

The results are presented as force and moment coefficients with lift, drag,
and pitching moment referred to the stability axis system and rolling moment,
yawing moment, and side force referred to the body axis system. The reference
center of moments was located at 53.0 percent of the body length behind the
nose, and at 1.25 percent of the body length below the body reference line.

b body reference span, 0.860 ft (0.262 m)

C_D drag coefficient, $\dfrac{\text{Drag}}{qS}$

C_L lift coefficient, $\dfrac{\text{Lift}}{qS}$

C_l rolling-moment coefficient, $\dfrac{\text{Rolling moment}}{qSb}$

C_{l_β} effective dihedral parameter, $\dfrac{\Delta C_l}{\Delta \beta}$

C_m pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qSl}$

C_n yawing-moment coefficient, $\dfrac{\text{Yawing moment}}{qSb}$

C_{n_β} directional stability parameter, $\dfrac{\Delta C_n}{\Delta\beta}$

C_Y side-force coefficient, $\dfrac{\text{Side force}}{qS}$

C_{Y_β} side-force parameter, $\dfrac{\Delta C_Y}{\Delta\beta}$

L/D lift-drag ratio, C_L/C_D

l body reference length, 1.333 ft (0.406 m)

M Mach number

q free-stream dynamic pressure, lbf/sq ft (N/m^2)

R Reynolds number

r radius, in. (cm)

S projected reference planform area, 0.634 sq ft (0.059 sq m)

x,y,z body coordinate axes

α angle of attack referred to body reference line, deg

β angle of sideslip referred to plane of symmetry, deg

δ_r rudder deflection angle, deg

MODELS

Details of the configuration are presented in figure 1 and ordinates defining the cross-section shape are given in table I. The model has a leading-edge sweep angle of 74°. Directional stability of the basic configuration is provided by two tip fins oriented at approximately 30° away from the vertical (designated D-1) and by a center fin with a 6° wedge section (designated E). (See fig. 1.)

The tip fins investigated are shown in figure 2; they consist of three fins of variable spans (designated H, I, and J in fig. 2(a)) and four fins of variable chords (designated D-1, F, G, and L in fig. 2(b)). The center fins investigated, shown in figure 3, include the basic center fin E, the basic center fin E with a trailing-edge-chord extension (designated fin N), fin E with a reduced span (designated fin K), and center fin N with a delta-shaped

end plate attached to the tip chord. A canopy, illustrated in figure 1, was also investigated.

A summary of the fin configurations investigated at Mach numbers from 1.50 to 2.86 and at a Mach number of 2.21 is presented in table II.

TESTS

The test conditions are summarized in the following table:

Facility	Mach number	Stagnation temperature,		Stagnation pressure,		Reynolds number per ft
		°F	°K	lbf/sq ft abs	kN/m²	
Langley Unitary Plan wind tunnel	1.50 1.80 2.16 2.86	150 150 150 150	339 339 339 339	1166 1246 1296 1629	56 60 62 78	2.10×10^6 2.10 1.84 1.57
Langley 4- by 4-foot super- sonic pressure tunnel	2.21	100	311	1510	72	2.38×10^6

The stagnation dewpoint was maintained sufficiently low in both phases of the investigation (-30° F or lower) so that no condensation effects were encountered in the test section. The angle of attack was corrected for deflection of the balance and sting under load. The Mach number variation did not exceed ± 0.015 in either test section, and the flow-angle variation in the horizontal and vertical planes was within about $\pm 0.1^\circ$ of the values used for reduction of data.

Force measurements were made through the use of a six-component internal strain-gage balance. The model was mounted in each test section on a remotely controlled variable-angle sting. The angle-of-attack range of the tests made at Mach numbers from 1.50 to 2.16 extended from about -4° to about 21° and to angles of attack of about 38° for a few runs. The angle-of-attack range of the tests made at a Mach number of 2.21 extended from about -7° to about 27°. In both phases of the investigation results were obtained at approximately 0° and 5° angles of sideslip throughout the angle-of-attack range in order to determine the lateral stability parameters C_{n_β}, C_{l_β}, and C_{Y_β}. The parameters were determined from these results by calculating a mathematical difference

between lateral coefficients at nominal sideslip angle of 0° and 5° and dividing this difference by the difference between the corrected angles of sideslip.

The accuracy of the individually measured quantities and coefficients, based on previous tunnel and balance calibrations and repeatability of the data, is estimated to be within the following limits:

C_L . . . . ± 0.01
C_m . . . . ± 0.004
C_D . . . . ± 0.001
C_l . . . . ± 0.002
C_Y . . . . ± 0.002
C_n . . . . ± 0.003

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

DISCUSSION

The principal discussion of the results relates to the lateral stability and, in particular, the effect of fin changes on the directional stability of the model. However, because of the interrelation of the longitudinal and lateral characteristics due to tip-fin roll-out, some considerations of interest in the longitudinal plane will also be discussed.

The results in figure 5 show that, in the longitudinal plane, the largest effect of changing the tip-fin span is on the lift-drag ratio. This variation

in lift-drag ratio is caused by the change in both the base drag and the pressure drag of the blunted tip fins. An increase in L/D of about 20 percent at an angle of attack of about 12° occurs as a result of shortening the tip-fin span, or changing from fin H to fin J. As may be expected, increasing the chord of tip fin D-1 in the rearward direction by adding longitudinal stabilizing area increases the stability. (See fig. 6, fins D-1 and L; and fig. 7, fins D-1, G, and F.)

The tip fins J, I, and H are compared in figure 8 with the fin designated D-1 in reference 3. The lateral stability characteristics show negative increments in C_{n_β} as the tip-fin span is decreased, but at angles of attack above about 24°, where C_{n_β} is the lowest, the configuration with the intermediate-span fin I maintains directional stability. Increasing the Mach number generally increases the directional stability for all fins in the higher angle-of-attack range. In addition, reductions in tip-fin span reduce the effective dihedral $\left(-C_{l_\beta}\right)$ of the configuration. The lateral stability characteristics obtained at a Mach number of 2.21 for various chord lengths of the tip fin D-1 (fig. 12) show that only neutral directional stability was attained with a 1-inch (2.54-cm) chord extension (fin F). Because of these results, a 1.5-inch (3.81-cm) extension (fin L) was investigated at Mach numbers from 1.50 to 2.86; results obtained using fin L are compared in figure 9 with results obtained using fin D-1. The results show that the configuration with fin L is directionally stable at $M = 2.16$ and appears to maintain stability for the higher angles of attack at all Mach numbers.

The directionally destabilizing effect of the canopy is large throughout the Mach number and angle-of-attack range (fig. 10). Opening deflectable panels on the sides of the center vertical tail 22.5° (or adding wedges) in order to increase the airfoil surface angle increases directional stability at all angles of attack and Mach numbers (fig. 10).

A chord extension to the center fin E (fin N) at a Mach number of 2.21 (fig. 12) increases directional stability throughout the angle-of-attack range, but the amount of stability created at the highest angles of attack is small. The addition of a delta-shaped end plate to the extended-chord center fin N also increases stability. The combined effects of both chord extension and end plate are not favorable enough to produce a directionally stable configuration at the higher angles of attack; the effects of span increase (fins H and I), however, are much more favorable in producing stability. (See fig. 8.)

CONCLUSIONS

An investigation of the aerodynamic characteristics of a model of a manned lifting entry vehicle, designated HL-10, with various fin arrangements at Mach numbers from 1.50 to 2.86 indicated the following conclusions:

1. Increasing either the tip-fin span or chord provided directional stability at the higher Mach numbers.

2. The most significant effects of the tip-fin arrangements on the longitudinal characteristics were the decreases in lift-drag ratio which resulted from increasing the tip-fin span and chord.

3. Increases in directional stability were produced by changes in the center vertical fin, which included a chord extension and addition of an end plate and trailing-edge wedge sections.

4. The canopy created a large unstable increment in directional stability for the basic vehicle.

Langley Research Center,
    National Aeronautics and Space Administration,
        Langley Station, Hampton, Va., July 30, 1965.

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x/l = 0.042

z/l	y/l
0.0541	0
.0532	.0083
.0503	.0167
.0441	.0250
.0375	.0306
.0333	.0338
.0250	.0390
.0167	.0431
.0083	.0459
0	.0476
-.0536	0

x/l = 0.083

z/l	y/l
0.0681	0
.0668	.0083
.0637	.0167
.0579	.0250
.0502	.0333
.0417	.0392
.0330	.0444
.0250	.0487
.0167	.0521
.0083	.0547
0	.0568
-.0083	.0585
-.0167	.0596
-.0752	0

x/l = 0.125

z/l	y/l
0.0737	0
.0729	.0083
.0702	.0167
.0660	.0250
.0594	.0330
.0505	.0417
.0417	.0477
.0333	.0528
.0250	.0571
.0167	.0604
.0083	.0632
0	.0656
-.0083	.0675
-.0167	.0691
-.0250	.0704
-.0333	.0714
-.0904	0

x/l = 0.167

z/l	y/l
0.0771	0
.0763	.0083
.0744	.0167
.0712	.0250
.0664	.0333
.0597	.0417
.0512	.0500
.0417	.0565
.0333	.0618
.0250	.0664
.0167	.0701
.0083	.0732
0	.0757
-.0083	.0778
-.0167	.0796
-.0250	.0811
-.0333	.0823
-.0417	.0833
-.0500	.0840
-.1026	0

x/l = 0.208

z/l	y/l
0.0792	0
.0787	.0083
.0772	.0167
.0747	.0250
.0712	.0333
.0664	.0416
.0592	.0500
.0517	.0583
.0417	.0656
.0333	.0713
.0250	.0760
.0167	.0800
.0083	.0833
0	.0860
-.0083	.0882
-.0167	.0902
-.0250	.0919
-.0333	.0933
-.0417	.0946
-.0500	.0955
-.0583	.0962
-.1126	0

x/l = 0.250

z/l	y/l
0.0807	0
.0803	.0083
.0792	.0167
.0773	.0250
.0748	.0333
.0712	.0417
.0666	.0500
.0606	.0583
.0527	.0667
.0458	.0721
.0417	.0754
.0333	.0811
.0250	.0862
.0167	.0902
.0083	.0937
0	.0965
-.0083	.0990
-.0167	.1011
-.0250	.1027
-.0333	.1044
-.0417	.1057
-.0500	.1067
-.0583	.1076
-.0667	.1083
-.1205	0

x/l = 0.292

z/l	y/l
0.0817	0
.0814	.0083
.0807	.0167
.0794	.0250
.0774	.0333
.0750	.0417
.0715	.0500
.0672	.0583
.0617	.0667
.0546	.0750
.0500	.0789
.0417	.0858
.0333	.0918
.0250	.0969
.0167	.1010
.0083	.1044
0	.1072
-.0083	.1098
-0.0167	.1119
-.0250	.1137
-.0333	.1156
-.0417	.1170
-.0500	.1182
-.0583	.1192
-.0667	.1198
-.0750	.1202
-.1268	0

x/l = 0.333

z/l	y/l
0.0820	0
.0818	.0083
.0813	.0167
.0803	.0250
.0789	.0333
.0771	.0417
.0747	.0500
.0716	.0583
.0677	.0667
.0627	.0750
.0564	.0833
.0485	.0917
.0417	.0968
.0333	.1027
.0250	.1078
.0167	.1119
.0083	.1152
0	.1179
-.0083	.1204
-.0167	.1227
-.0250	.1250
-.0333	.1267
-.0417	.1282
-.0500	.1296
-.0583	.1306
-.0667	.1317
-.0750	.1321
-.1312	0

x/l = 0.375

z/l	y/l
0.0821	0
.0820	.0083
.0816	.0167
.0809	.0250
.0799	.0333
.0783	.0417
.0766	.0500
.0744	.0583
.0714	.0667
.0679	.0750
.0633	.0833
.0576	.0917
.0503	.1000
.0415	.1083
.0333	.1136
.0250	.1187
.0167	.1229
.0083	.1262
0	.1292
-.0083	.1315
-.0167	.1337
-.0250	.1358
-.0333	.1377
-.0417	.1394
-.0500	.1408
-.0583	.1420
-.0667	.1429
-.0750	.1437
-.0833	.1442
-.1334	0

x/l = 0.417

z/l	y/l
0.0814	0
.0813	.0083
.0811	.0167
.0805	.0250
.0797	.0333
.0786	.0417
.0772	.0500
.0755	.0583
.0733	.0667
.0706	.0750
.0674	.0833
.0633	.0917
.0582	.1000
.0517	.1083
.0437	.1167
.0375	.1211
.0333	.1241
.0250	.1296
.0167	.1339
.0083	.1375
0	.1406
-.0083	.1431
-.0167	.1453
-.0250	.1472
-.0333	.1492
-.0417	.1508
-.0500	.1523
-.0583	.1536
-.0667	.1546
-.0750	.1554
-.0833	.1559
-.1340	0

x/l = 0.458

z/l	y/l
0.0800	0
.0799	.0083
.0797	.0167
.0794	.0250
.0788	.0333
.0780	.0417
.0768	.0500
.0755	.0583
.0739	.0667
.0720	.0750
.0694	.0833
.0664	.0917
.0629	.1000
.0581	.1083
.0526	.1167
.0453	.1250
.0363	.1333
.0292	.1379
.0250	.1407
.0167	.1454
.0083	.1491
0	.1521
-.0083	.1549
-.0167	.1571
-.0250	.1592
-.0333	.1611
-.0417	.1627
-.0500	.1642
-.0583	.1654
-.0667	.1664
-.0750	.1672
-.0833	.1677
-.1322	0

x/l = 0.500

z/l	y/l
0.0782	0
.0782	.0167
.0780	.0250
.0776	.0333
.0770	.0417
.0762	.0500
.0751	.0583
.0738	.0667
.0723	.0750
.0705	.0833
.0682	.0917
.0655	.1000
.0620	.1083
.0579	.1167
.0529	.1250
.0467	.1333
.0390	.1417
.0333	.1458
.0250	.1521
.0167	.1571
.0083	.1612
0	.1643
-.0083	.1672
-.0167	.1694
-.0250	.1715
-.0333	.1733
-.0417	.1750
-.0500	.1763
-.0583	.1775
-.0667	.1785
-.0750	.1792
-.1285	0

x/l = 0.542

z/l	y/l
0.0759	0
.0759	.0166
.0758	.0249
.0756	.0332
.0752	.0415
.0747	.0498
.0740	.0581
.0730	.0664
.0718	.0747
.0705	.0830
.0688	.0913
.0666	.0996
.0642	.1079
.0611	.1162
.0575	.1245
.0530	.1328
.0476	.1411
.0410	.1494
.0326	.1577
.0249	.1629
.0166	.1685
.0083	.1729
0	.1764
-.0083	.1790
-.0166	.1815
-.0249	.1834
-.0332	.1853
-.0415	.1869
-.0498	.1882
-.0581	.1893
-.0664	.1902
-.1229	0

x/l = 0.583

z/l	y/l
0.0741	0
.0741	.0104
.0740	.0271
.0735	.0437
.0726	.0604
.0710	.0771
.0671	.0937
.0668	.1020
.0651	.1104
.0626	.1187
.0596	.1270
.0563	.1354
.0521	.1437
.0471	.1520
.0412	.1604
.0337	.1687
.0250	.1756
.0167	.1813
.0083	.1860
0	.1897
-.0083	.1926
-.0167	.1949
-.0250	.1970
-.0333	.1988
-.0417	.2003
-.0500	.2017
-.0583	.2028
-.1156	0

x/l = 0.625

z/l	y/l
0.0716	0
.0716	.0104
.0716	.0271
.0713	.0437
.0707	.0604
.0696	.0771
.0678	.0937
.0655	.1104
.0637	.1187
.0616	.1270
.0591	.1354
.0558	.1437
.0521	.1520
.0478	.1604
.0429	.1687
.0365	.1770
.0292	.1842
.0250	.1878
.0167	.1941
.0083	.1991
0	.2028
-.0083	.2057
-.0167	.2080
-.0250	.2101
-.0333	.2118
-.0417	.2132
-.0500	.2143
-.1073	0

x/l = 0.667

z/l	y/l
0.0687	0
.0686	.0208
.0686	.0375
.0684	.0541
.0678	.0708
.0669	.0875
.0655	.1041
.0634	.1208
.0601	.1374
.0580	.1458
0.0553	.1541
.0522	.1624
.0483	.1708
.0439	.1791
.0385	.1874
.0317	.1958
.0250	.2015
.0167	.2080
.0083	.2128
0	.2167
-.0083	.2197
-.0167	.2218
-.0250	.2237
-.0333	.2254
-.0417	.2264
-.0986	0

x/l = 0.708

z/l	y/l
0.0654	0
.0653	.0417
.0651	.0583
.0650	.0750
.0643	.0916
.0634	.1083
.0617	.1250
.0596	.1416
.0582	.1499
.0563	.1583
.0542	.1666
.0517	.1749
.0487	.1833
.0446	.1916
.0398	.1999
.0340	.2083
.0292	.2130
.0250	.2168
.0167	.2235
.0083	.2283
0	.2317
-.0083	.2343
-.0167	.2363
-.0250	.2378
-.0333	.2390
-.0889	0

x/l = 0.750

z/l	y/l
0.0617	0
.0616	.0625
.0615	.0791
.0611	.0958
.0606	.1125
.0596	.1291
.0581	.1458
.0561	.1624
.0533	.1791
.0488	.1958
.0458	.2041
.0421	.2124
.0372	.2207
.0333	.2256
.0292	.2307
.0250	.2347
.0167	.2409
.0083	.2447
0	.2470
-.0083	.2491
-.0167	.2504
-.0250	.2511
-.0785	0

x/l = 0.792

z/l	y/l
0.0578	0
.0577	.0937
.0576	.1104
.0573	.1270
.0569	.1437
.0561	.1604
.0549	.1770
.0532	.1937
.0506	.2103
.0486	.2187
.0460	.2270
.0425	.2353
.0375	.2437
.0333	.2481
.0250	.2551
.0167	.2588
.0083	.2611
0	.2624
-.0083	.2631
-.0167	.2634
-.0673	0

x/l = 0.833

z/l	y/l
0.0536	0
.0534	.1666
.0532	.1833
.0528	.1999
.0521	.2166
.0510	.2332
.0482	.2499
.0455	.2582
.0400	.2666
.0333	.2707
.0250	.2736
.0167	.2749
.0083	.2753
0	.2753
-.0563	0

x/l = 0.875

z/l	y/l
0.0487	0
-.0452	0

x/l = 0.917

z/l	y/l
0.0440	0
-.0341	0

x/l = 0.958

z/l	y/l
0.0392	0
-.0227	0

x/l = 1.000

z/l	y/l
0.0344	0
-.0125	0

TABLE II.- FIN CONFIGURATIONS INVESTIGATED[1]

Test at Mach number:	Configuration description	Tip-fin designation	Center-fin designation
1.50, 1.80, 2.16, and 2.86	Basic	D-1	E
	Tip-fin span variable	H, I, J	E
	1.5-inch (3.81-cm) chord extension to fin D-1	L	E
	Short-span fin E	K	E
2.21	Chord variable	D-1, F, and G	E
	Chord extension to fin E	D-1	N
	End plate	D-1	N + End plate

[1]In addition to fin configurations, a canopy was investigated with fins D-1 and E.

View of tip fin D-1 in chord plane

Section A-A
Trailing-edge panels deflected

Figure 1.- Basic configuration. Dimensions are given first in inches and parenthetically in centimeters.

A

Rear view

Fin H

30.1°

Fin I

5.000 (12.70)

Fin J

3.500
(8.89)

50.8°

2.500

58.3° (6.35)
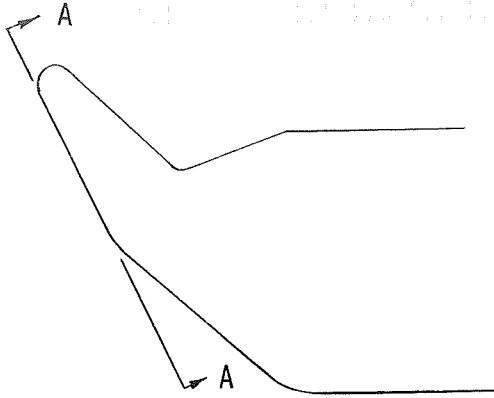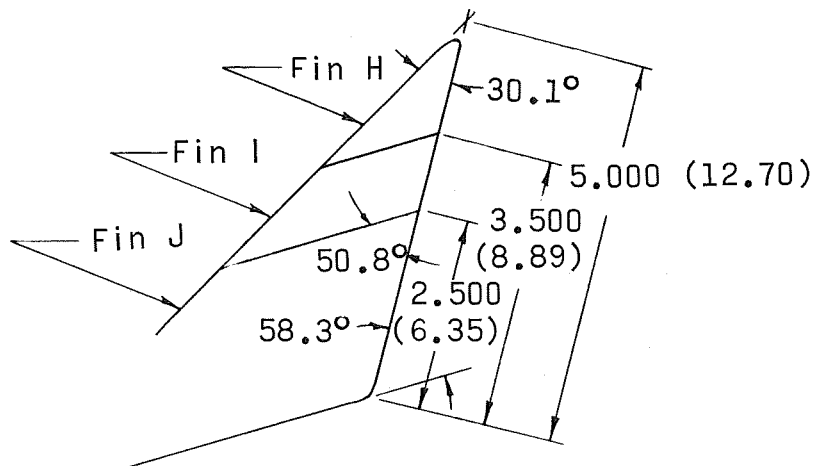
Section A-A

(a) Various spans.

Figure 2.- Drawing of tip fins. Dimensions are given first in inches and parenthetically in centimeters.

Rear view

Section A-A

1.820
(4.62)

1.970
(5.00)

47°

54°

2.125 (5.40)

0.500 (1.27)

1.000 (2.54)

Fin D-1

Fin F

Fin G

Fin L
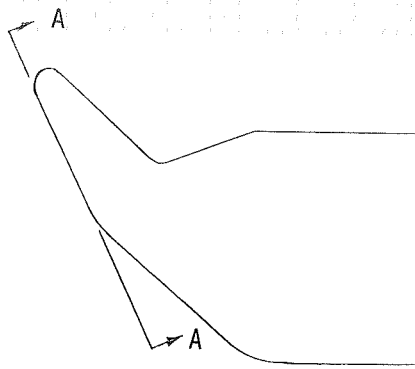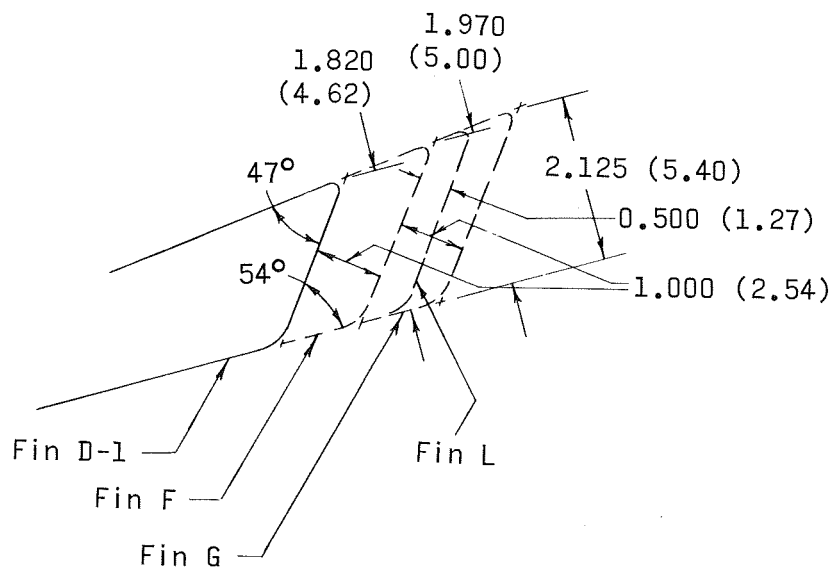
Section A-A

(b) Various chords.

Figure 2.- Concluded.

Fin E

1.080 (2.74)

A

Fin K

3.100 (7.87)

1.910
(4.85)

1.860
(4.72)

3°

Fins E and K

Section A-A

0.630 (1.60)

1.710 (4.34)

B

B

45°

Body trailing
edge

Fin N

Section B-B

0.063 (0.16)

50.8°

Fin N with
end plate

Top view
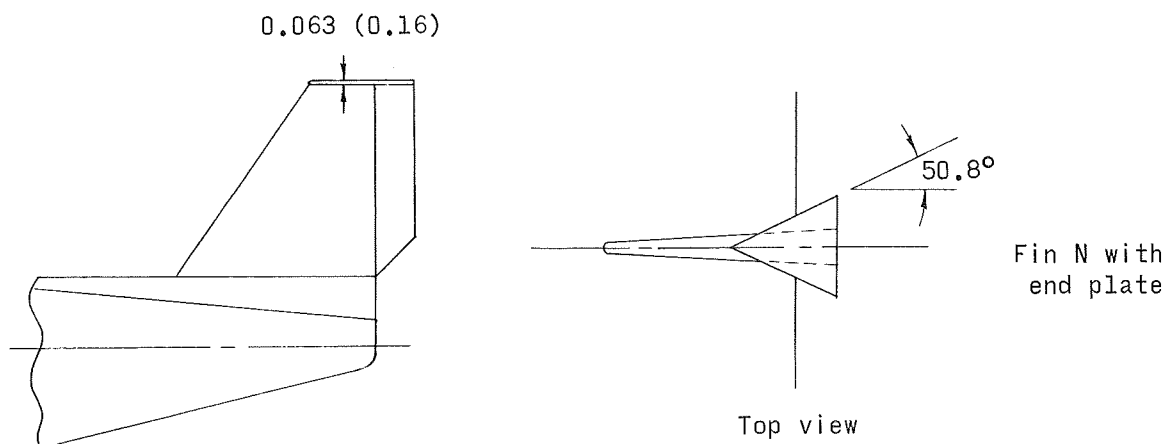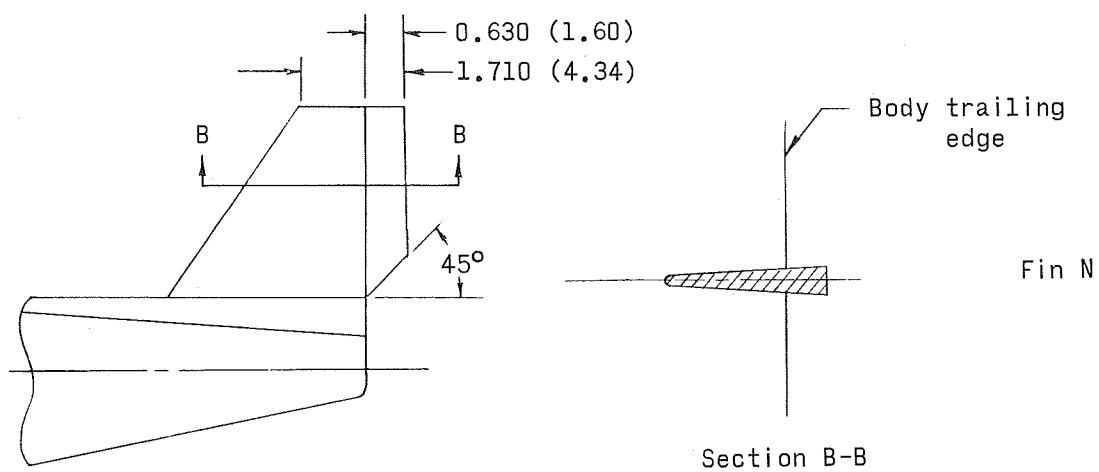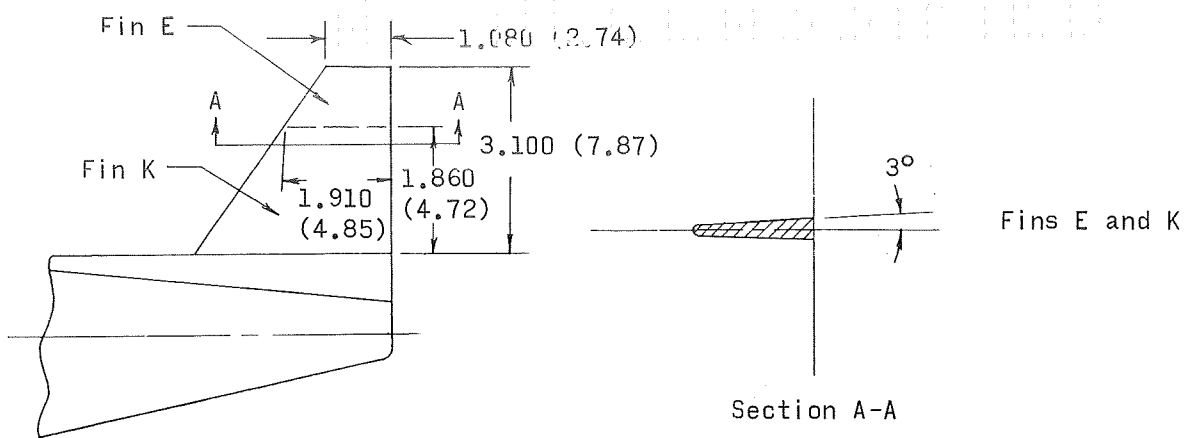
Figure 3.- Drawing of center fins.   Dimensions are given first in inches and parenthetically in centimeters.
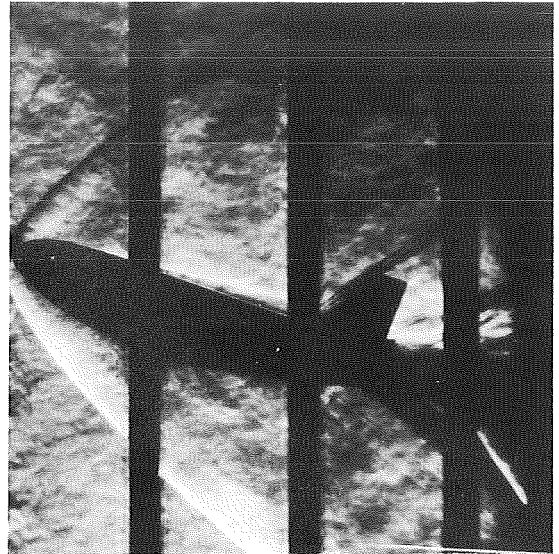
M = 1.50   M = 1.80
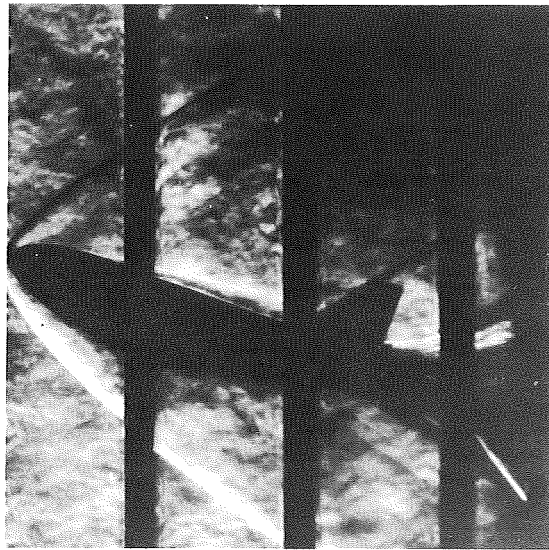
M = 2.16

Figure 4.- Schlieren photographs of test model. $\alpha = 21.06^{0}$.   L-65-166
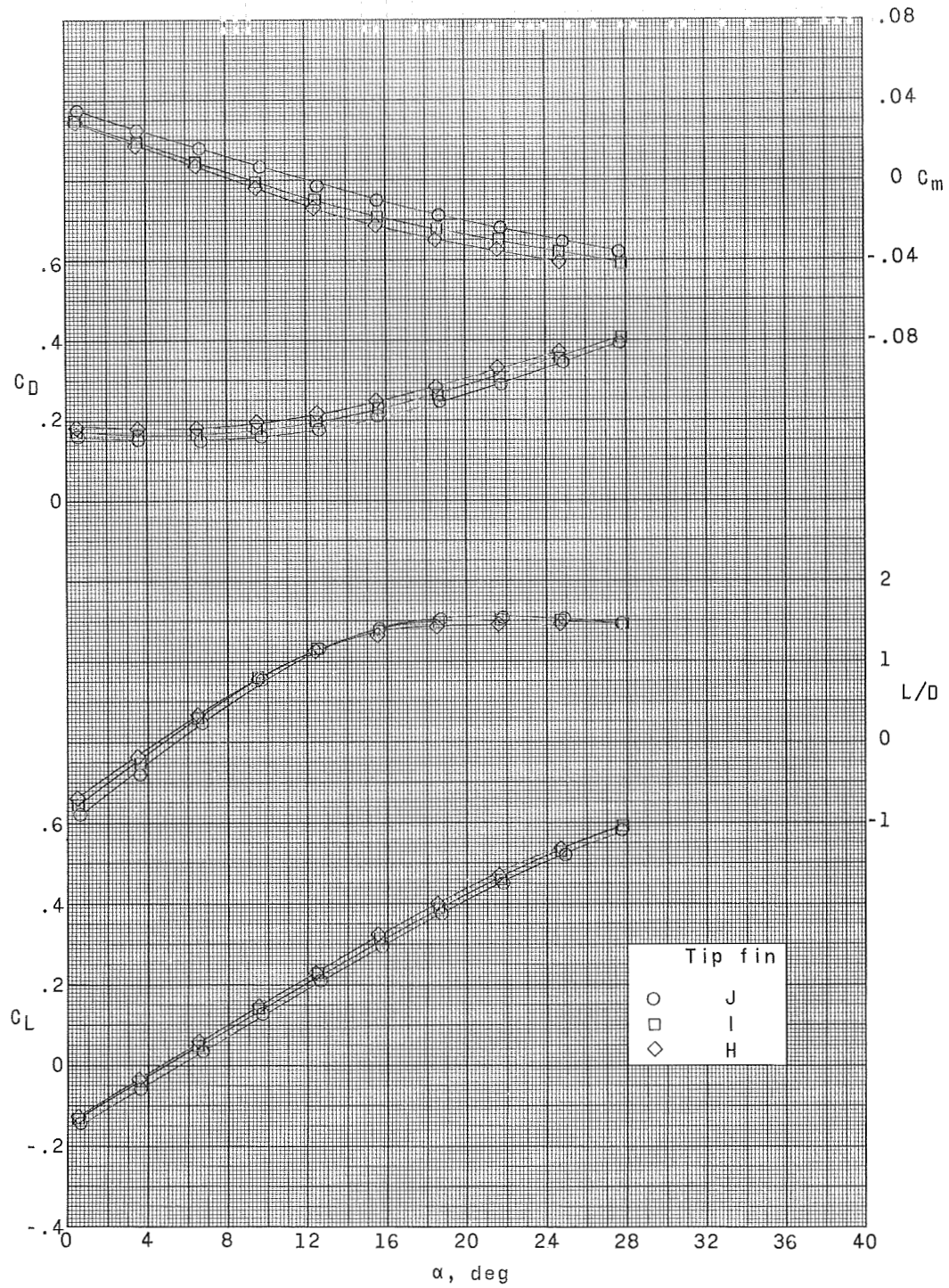
(a) M = 1.50.

Figure 5.- Pitch characteristics of model with various spans of tip fins.   Center fin E.
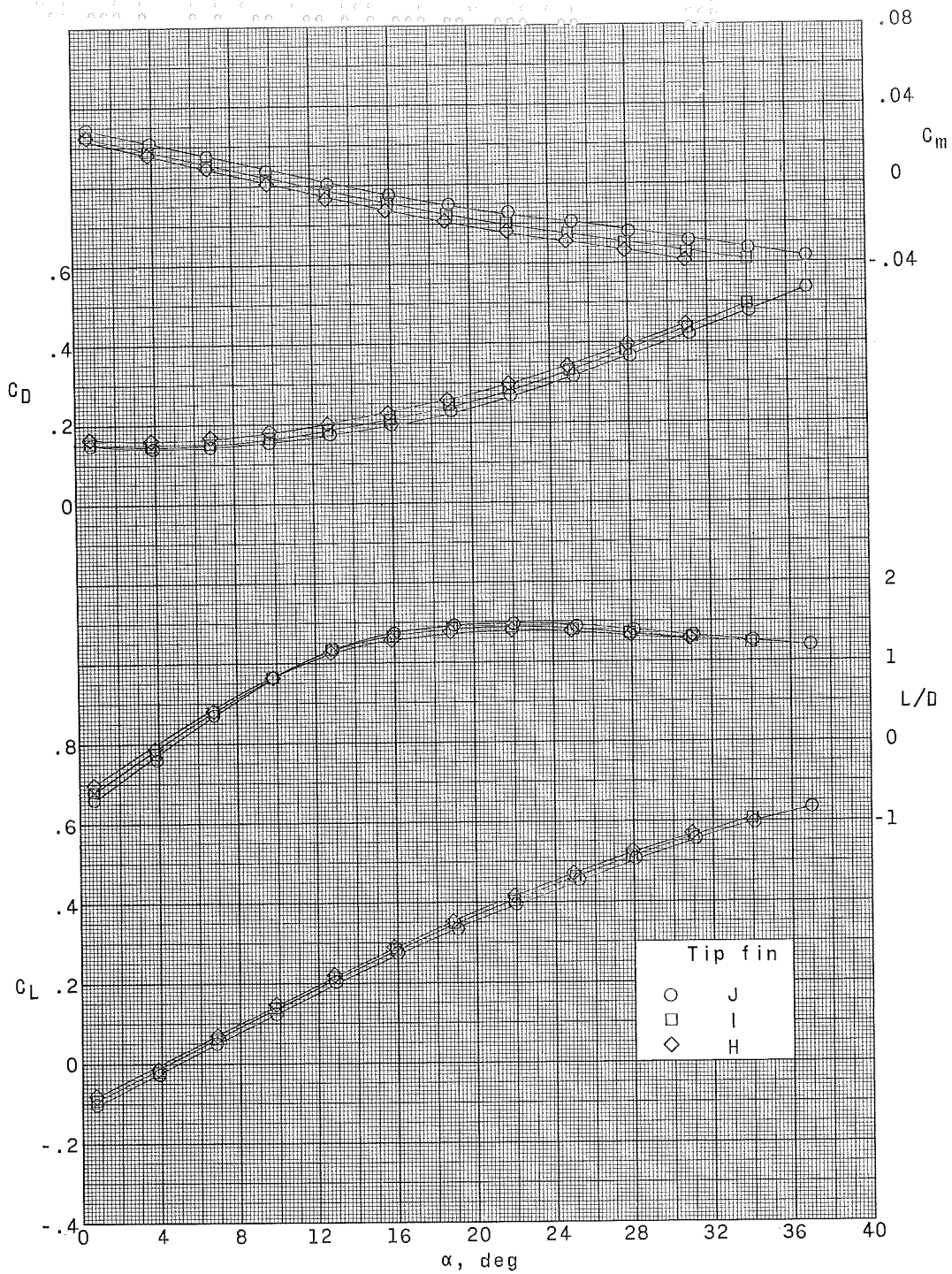
(b) M = 1.80.

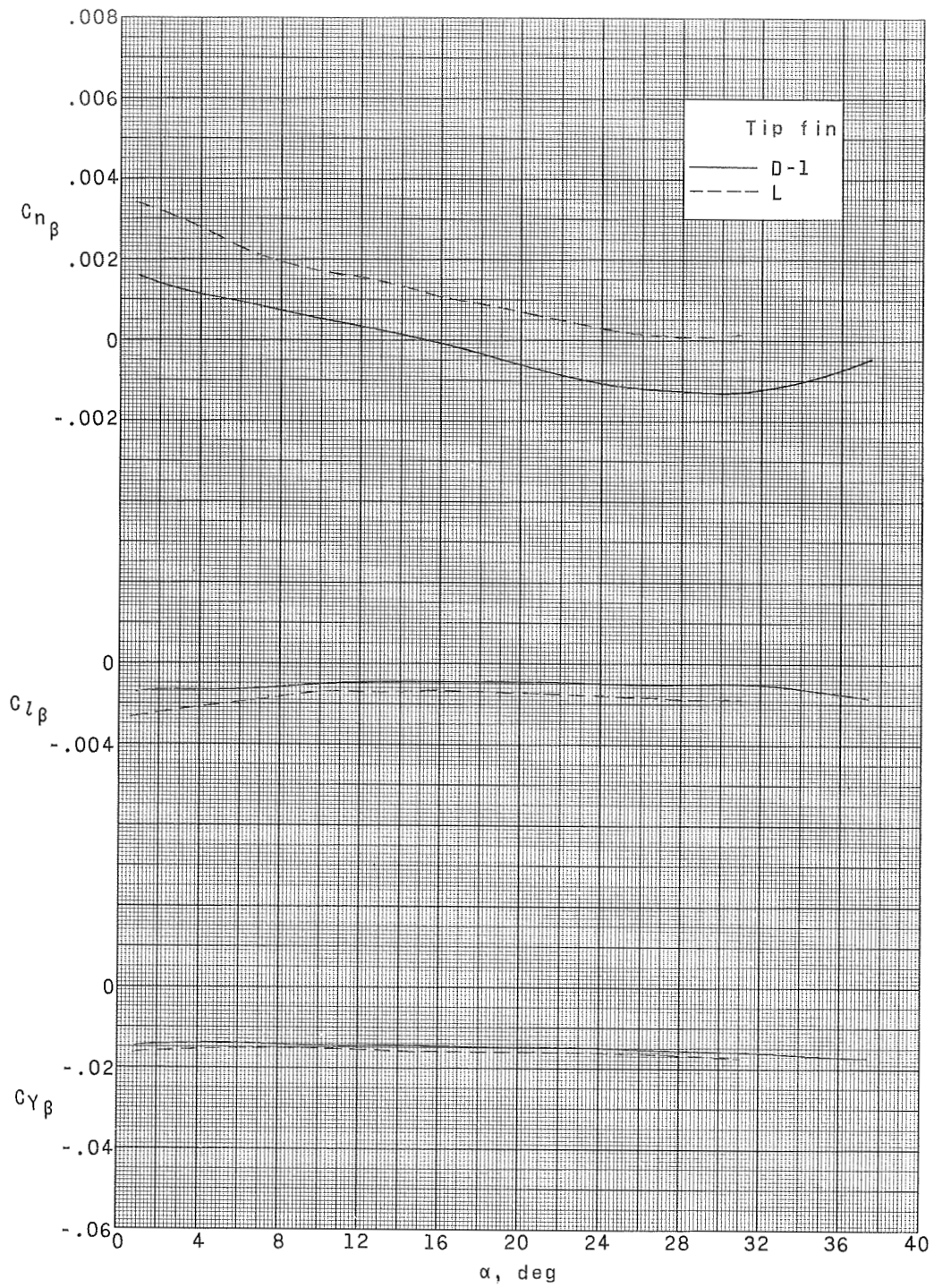Figure 5.- Continued.
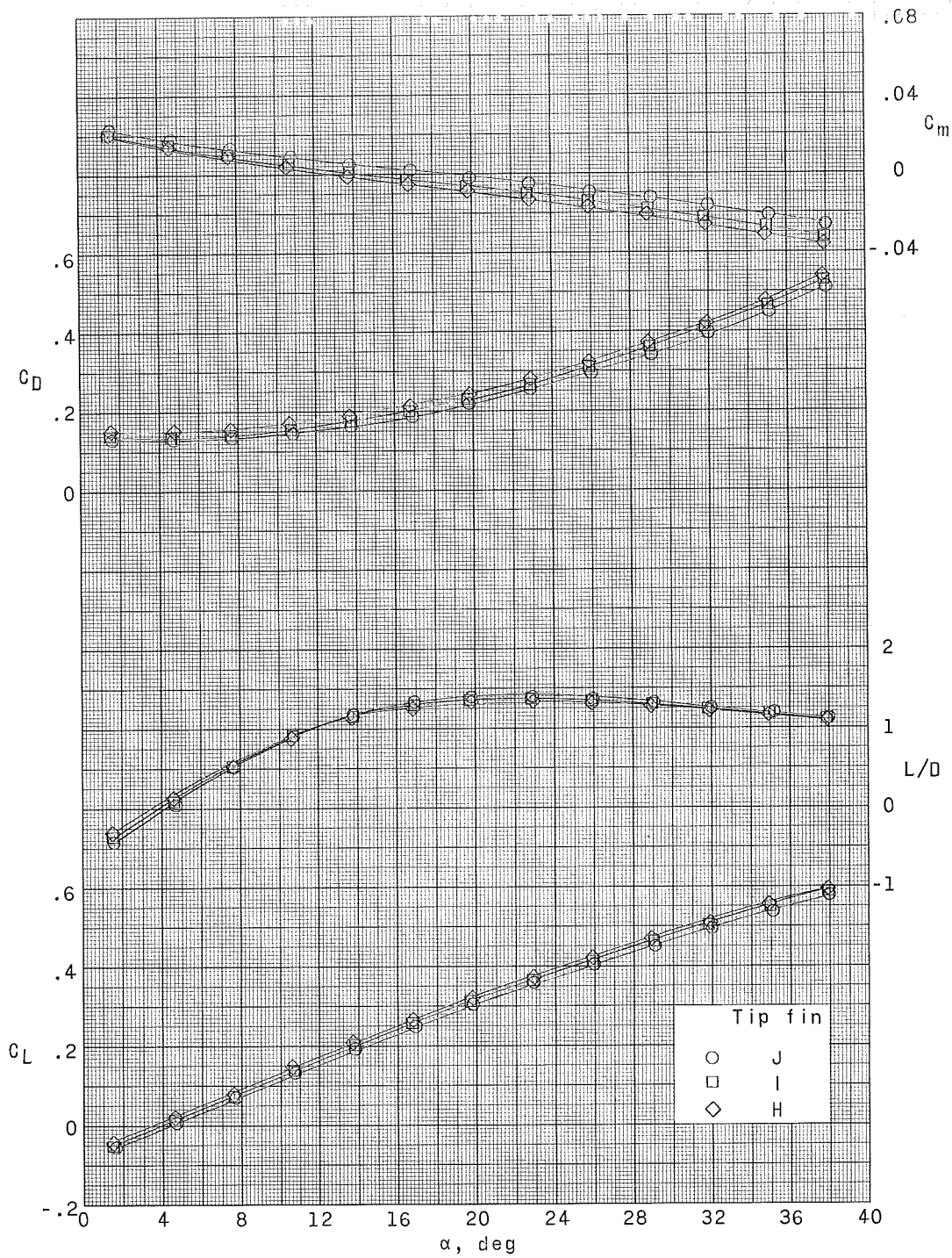
(c) M = 2.16.

Figure 5.- Continued.
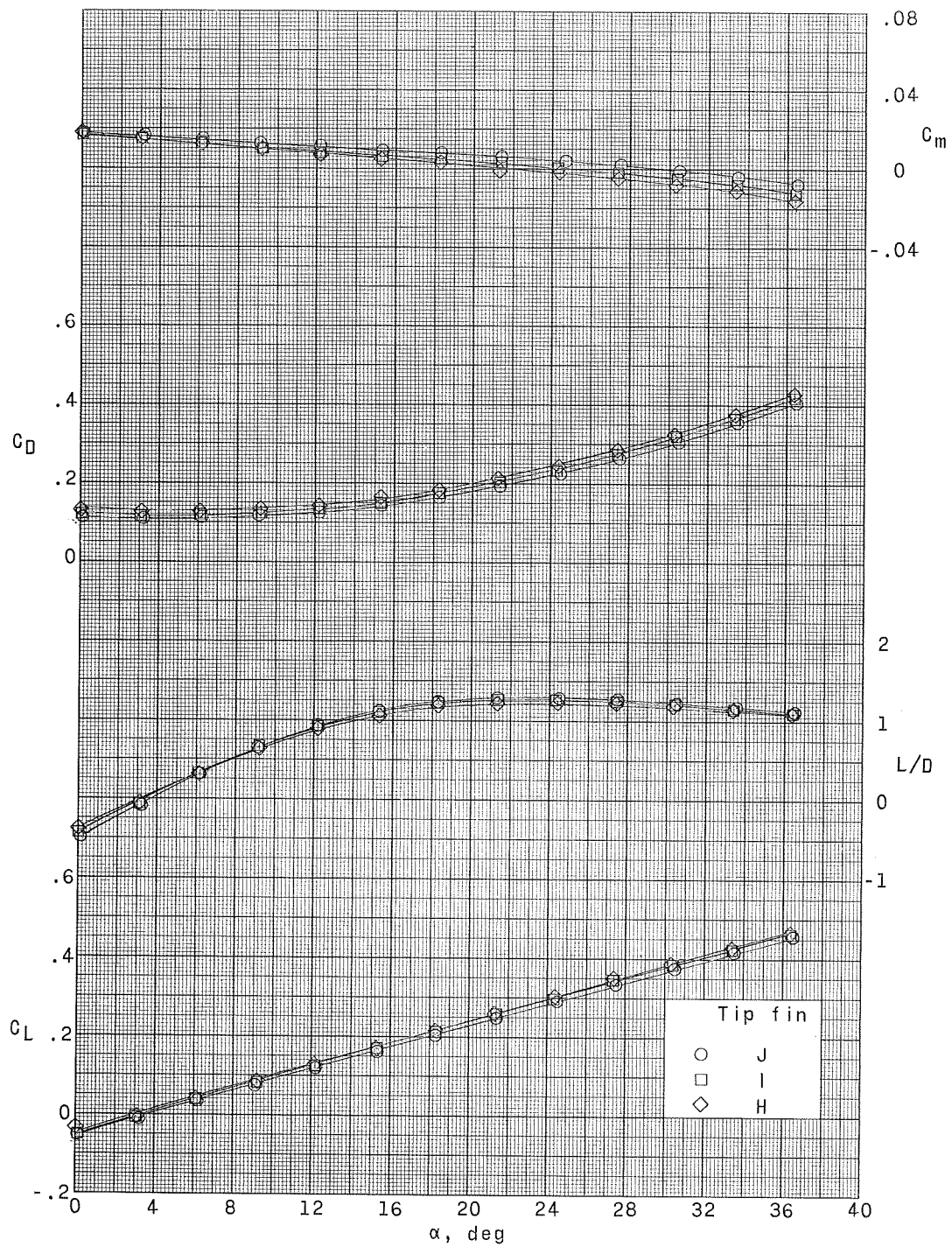
(d) M = 2.86.

Figure 5.- Concluded.
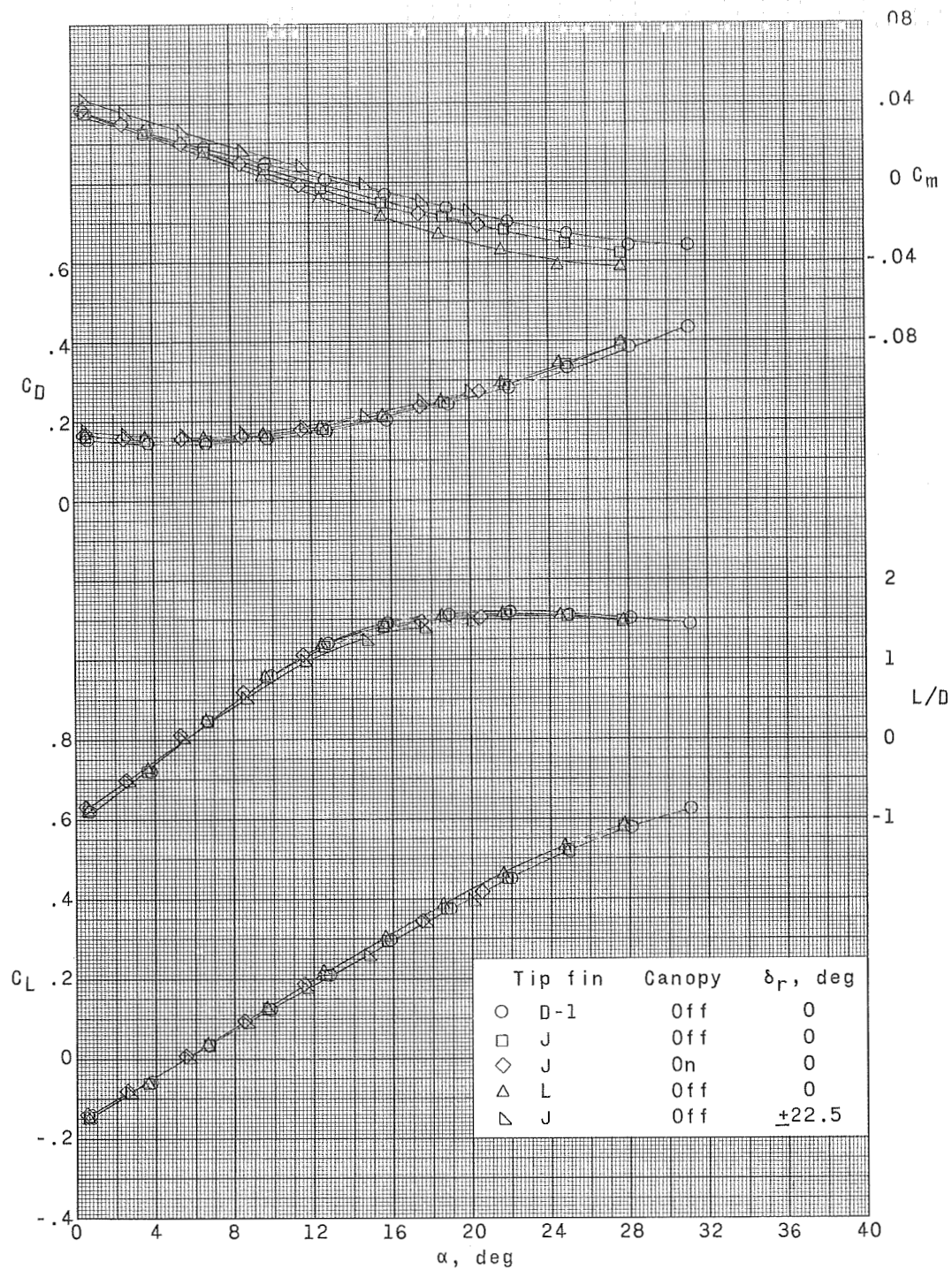
(a) M = 1.50.

Figure 6.- Pitch characteristics of model with extended-chord tip fins, canopy, and opposite deflection of rudder panels.   Center fin E.

Tip fin	Canopy	δ_r, deg
○ D-1	Off	0
□ J	Off	0
◇ J	On	0
△ L	Off	0
◁ J	Off	± 22.5
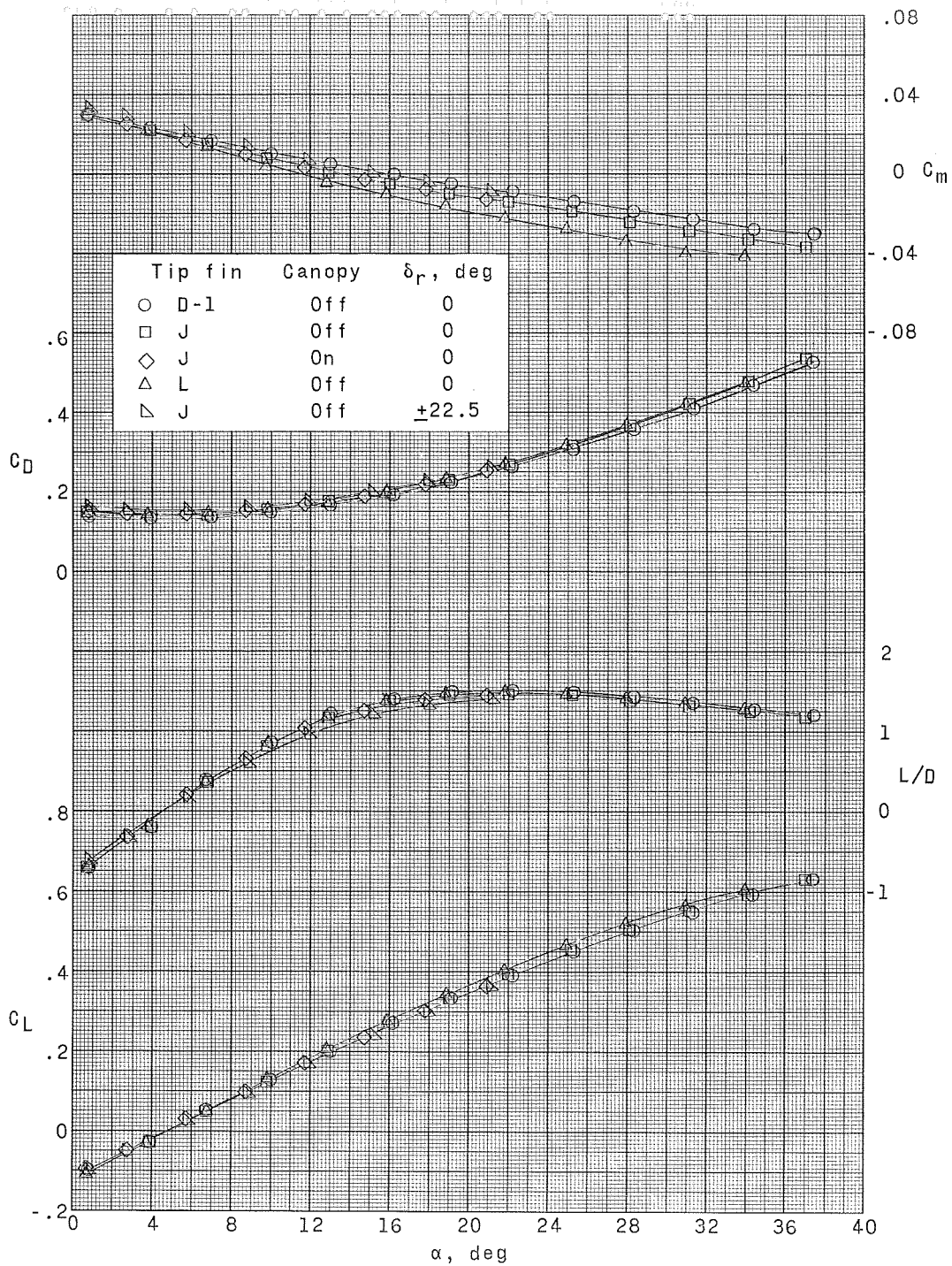
(b) M = 1.80.

Figure 6.- Continued.

(c) M = 2.16.

Figure 6.- Continued.

Tip fin	Canopy	δ_r, deg
○ D-1	Off	0
□ J	Off	0
△ L	Off	0
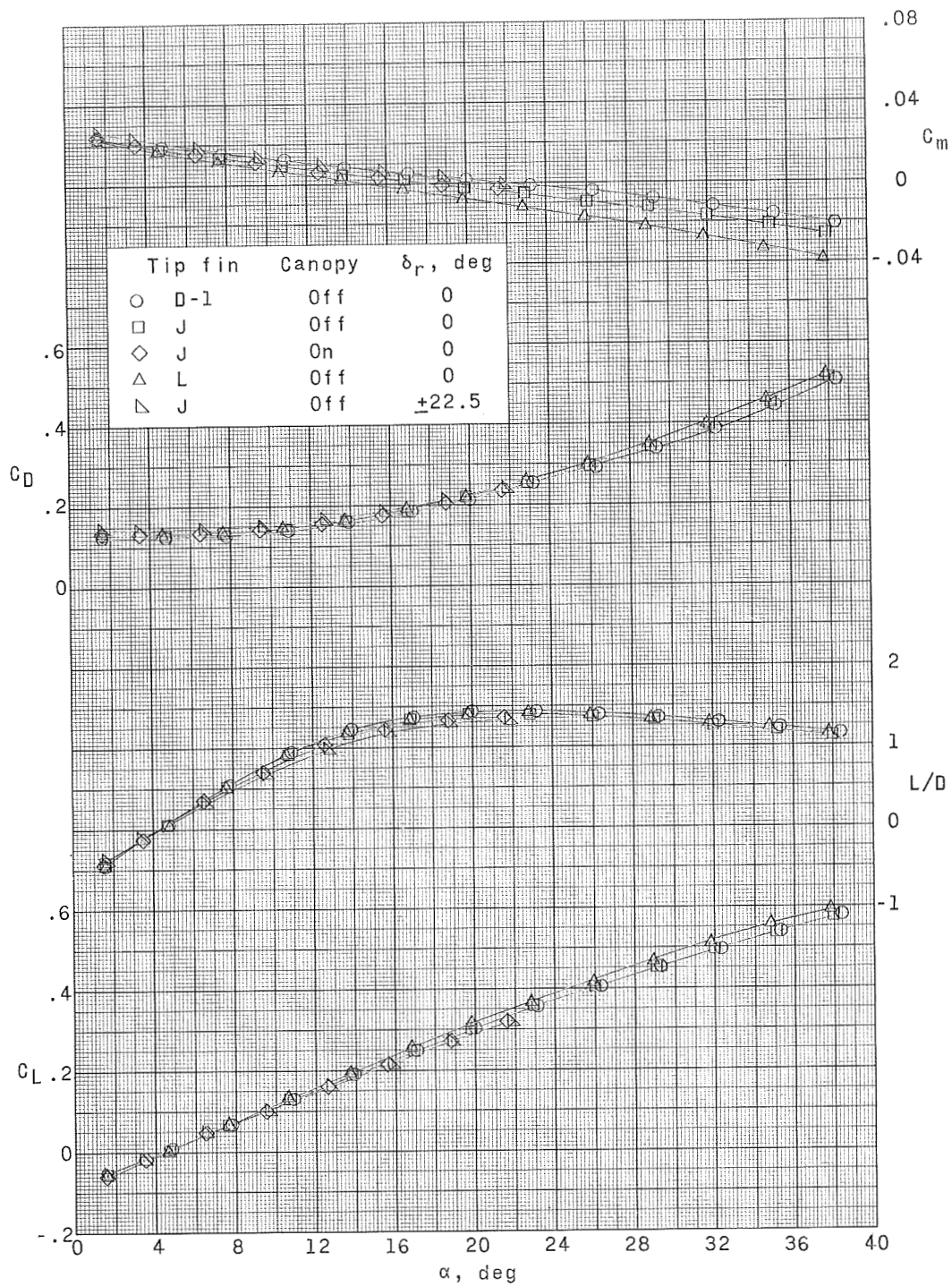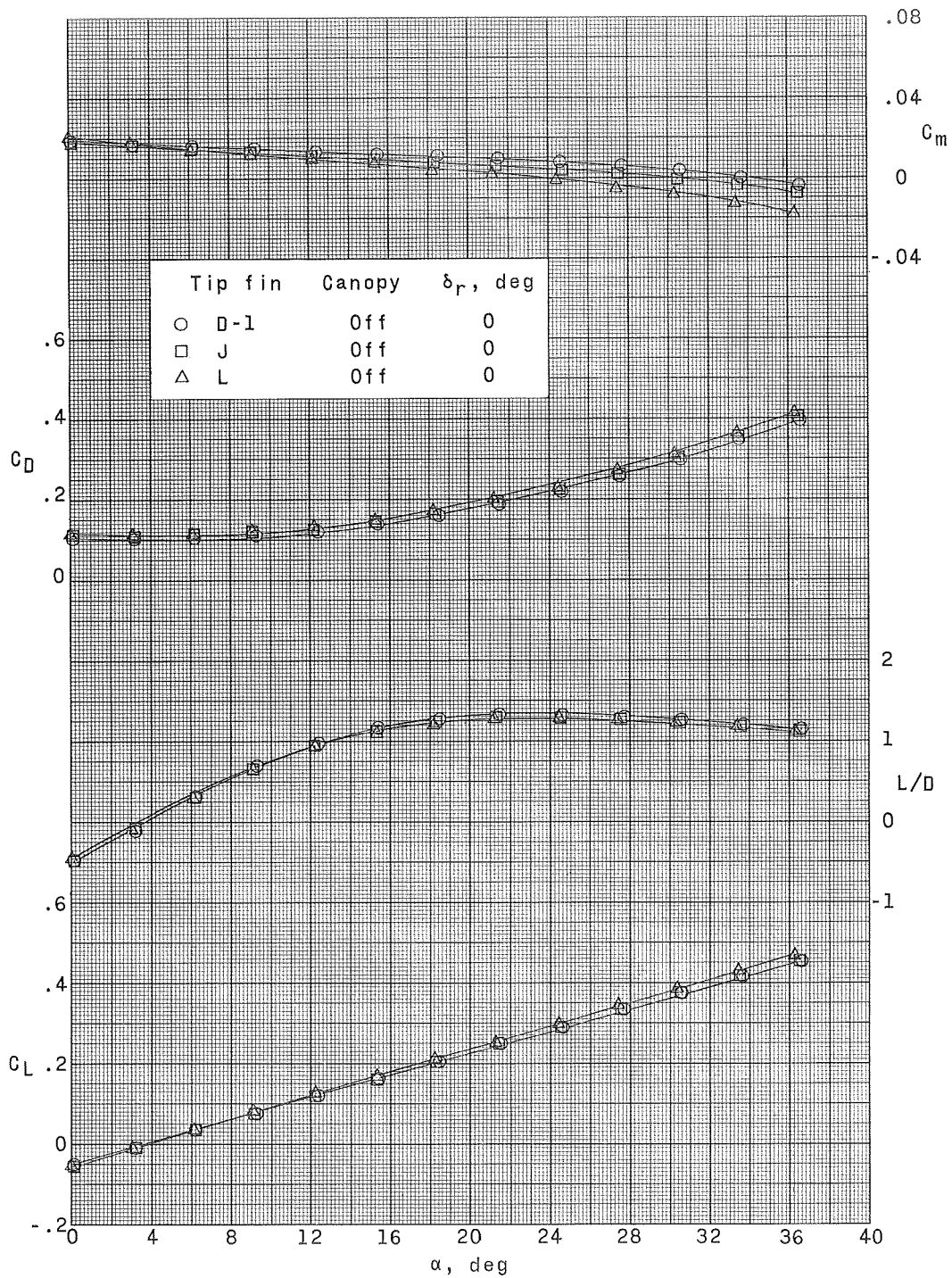
(d) M = 2.86.

Figure 6.- Concluded.
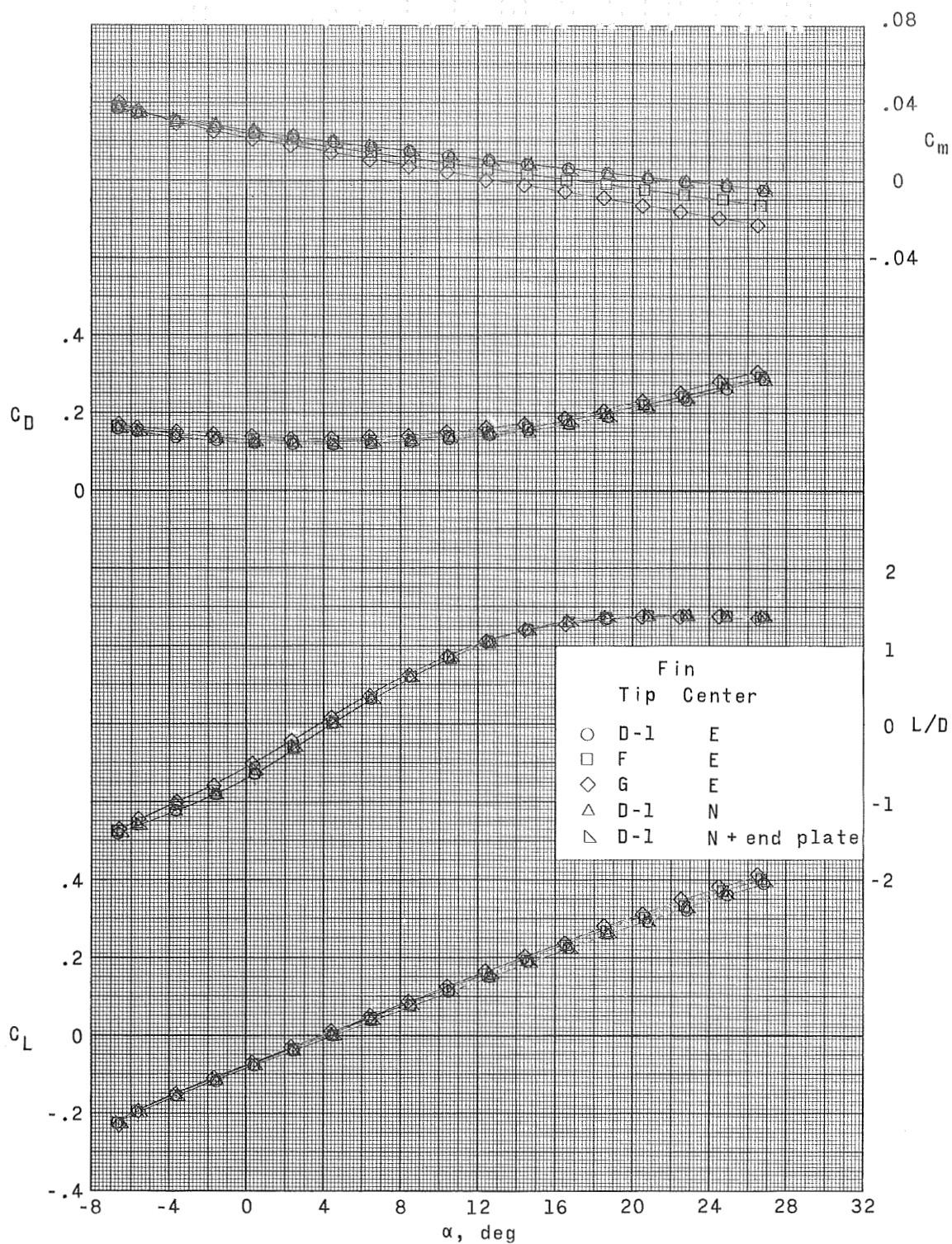
Figure 7.- Pitch characteristics of model with extended-chord tip and center fins, and end plate on center fin. M = 2.21.
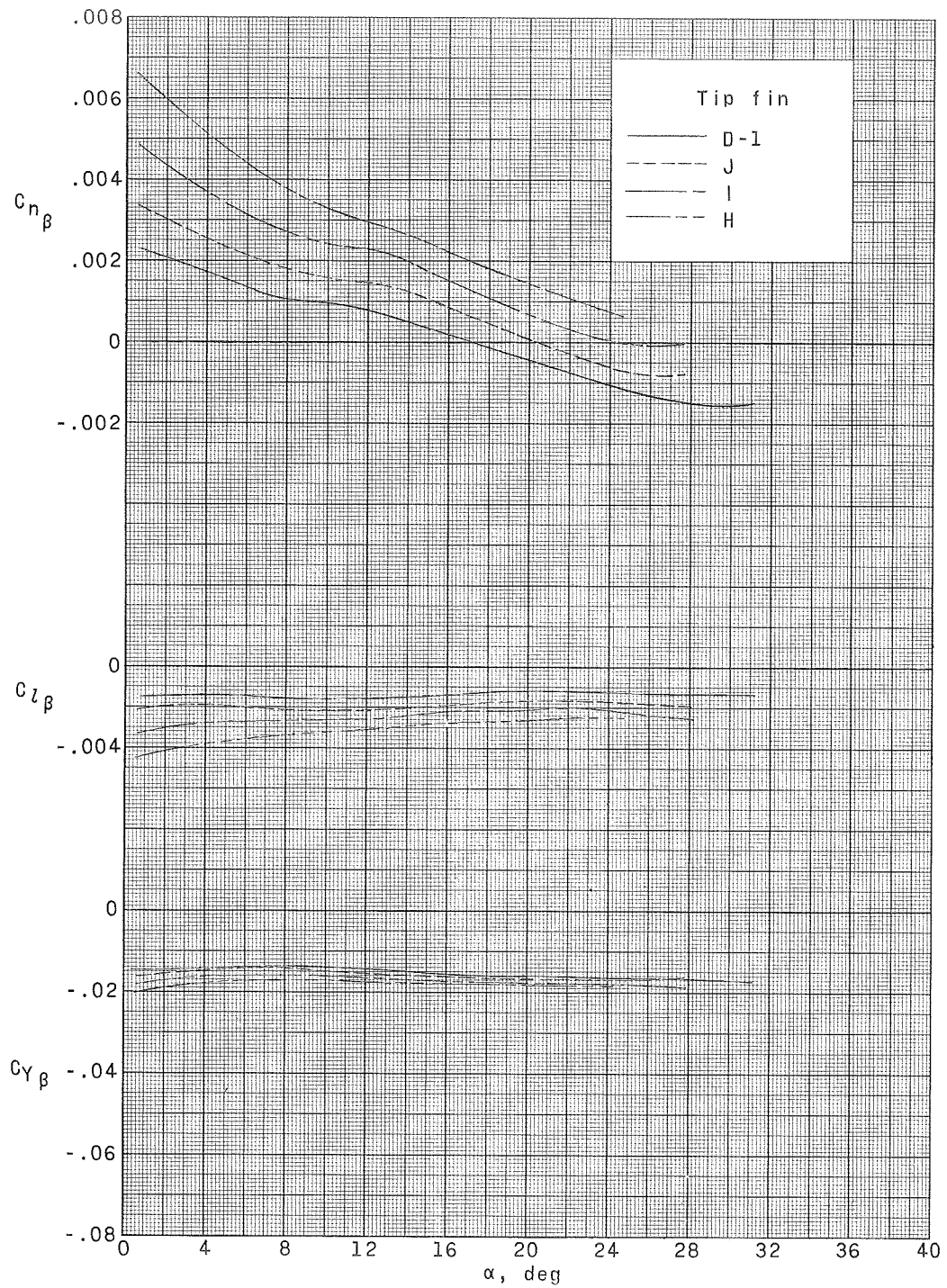
(a) M = 1.50.

Figure 8.- Lateral stability characteristics of model with various spans of tip fins.   Center fin E.
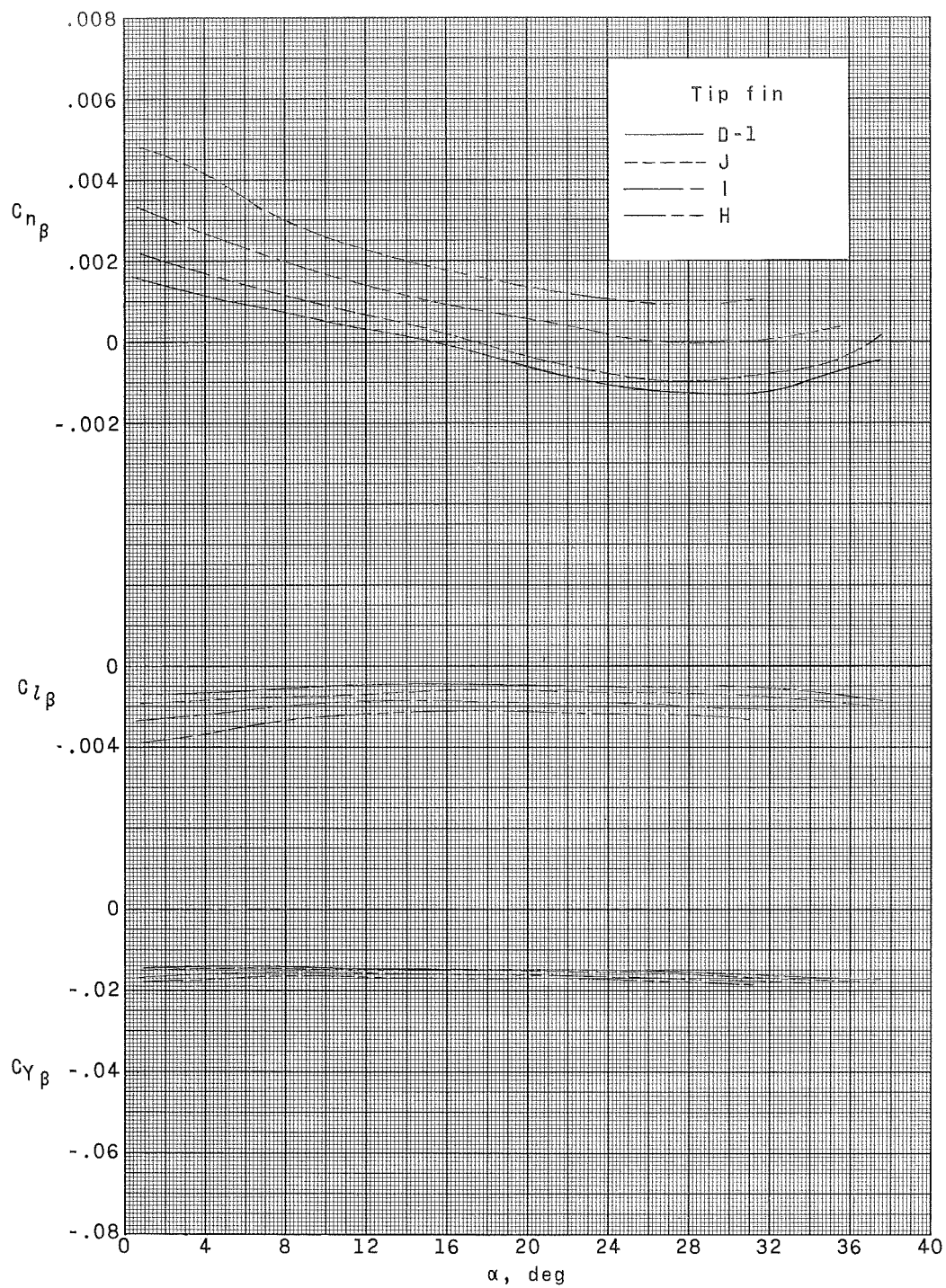
(b) M = 1.80.

Figure 8.- Continued.
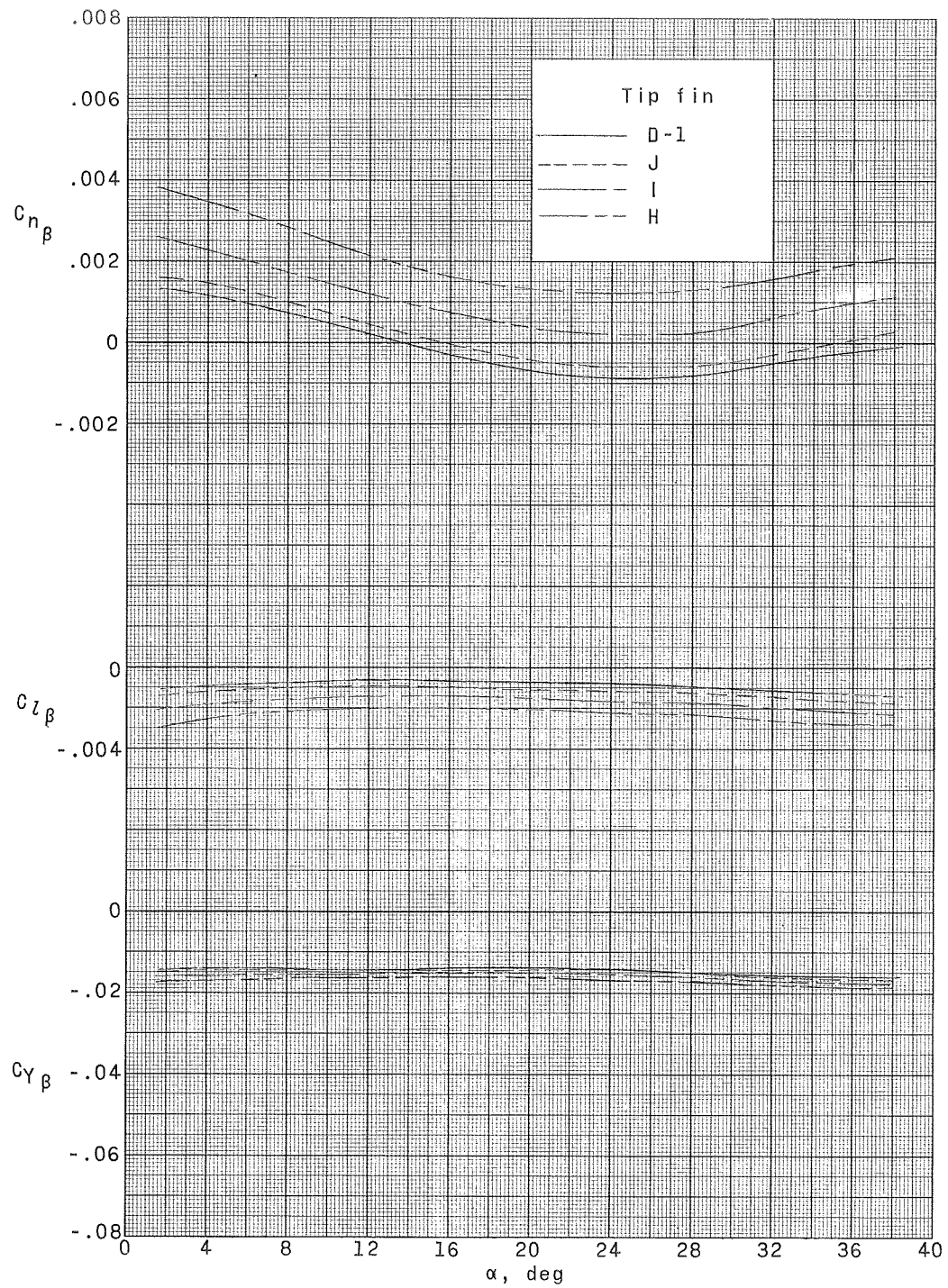
(c) M = 2.16.

Figure 8.- Continued.
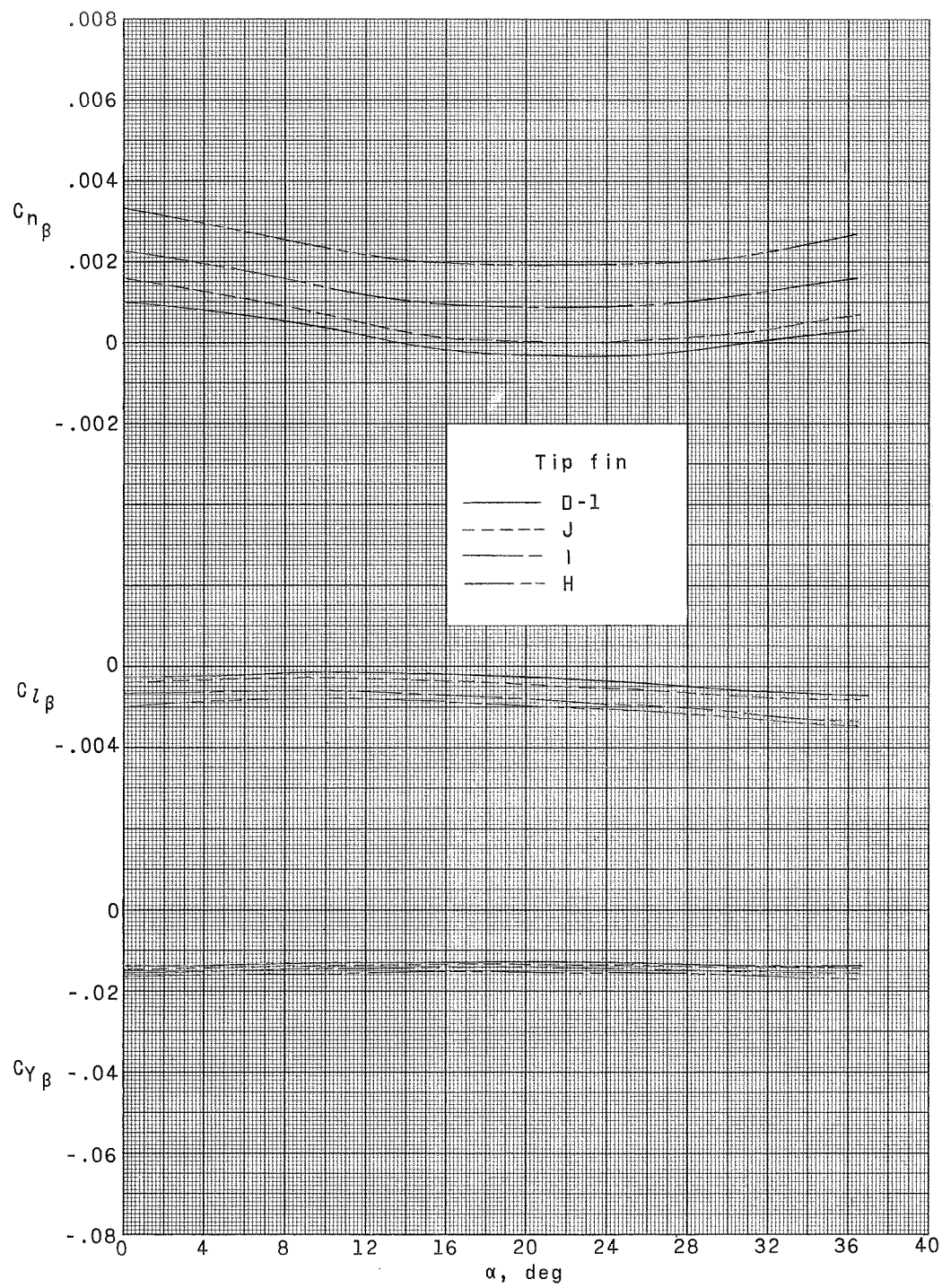
(d) M = 2.86.

Figure 8.- Concluded.
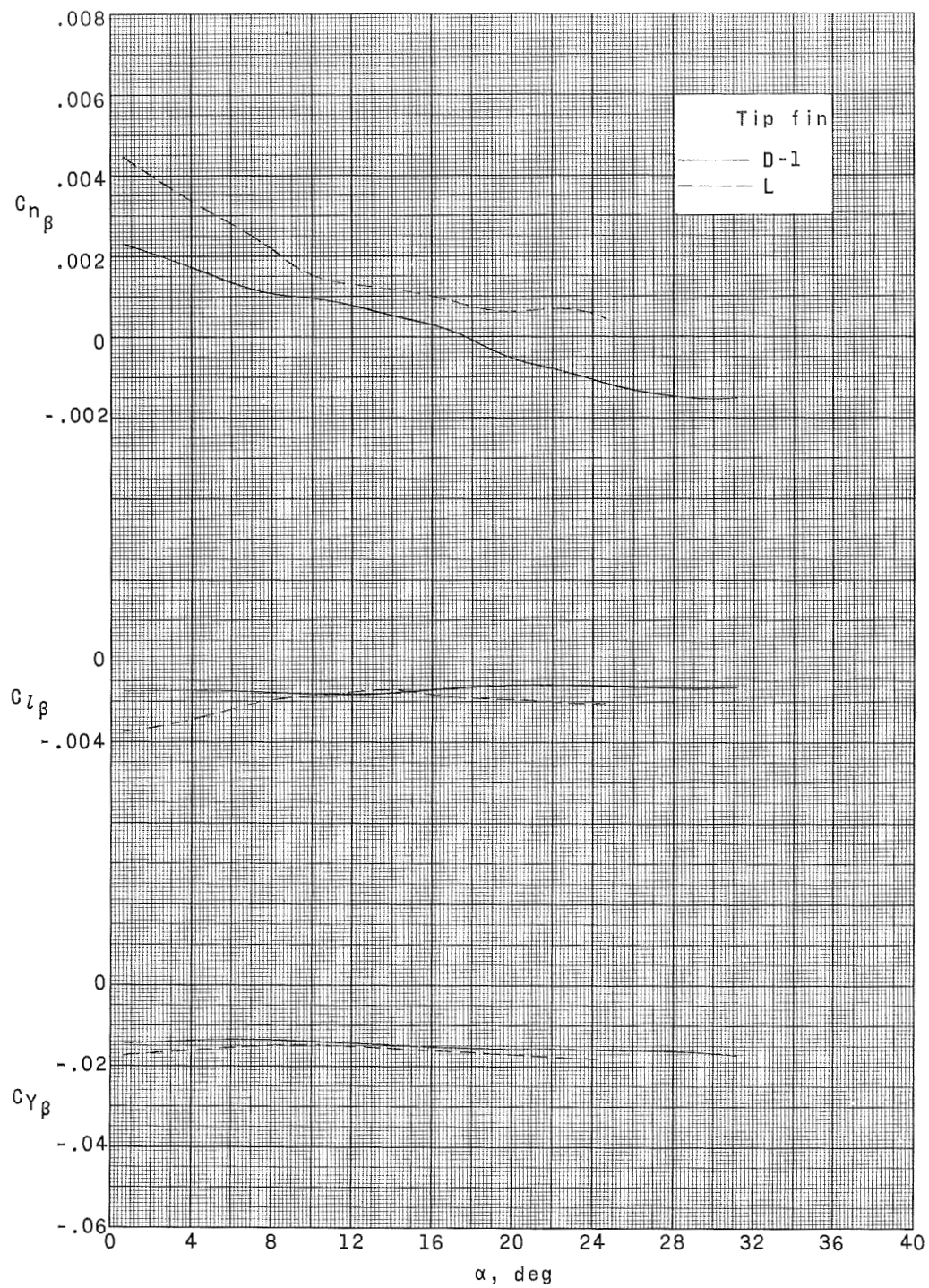
(a) M = 1.50.

Figure 9.- Lateral stability characteristics of model with 1.5-inch chord extension to tip fins.   Center fin E.

(b) M = 1.80.

Figure 9.- Continued.
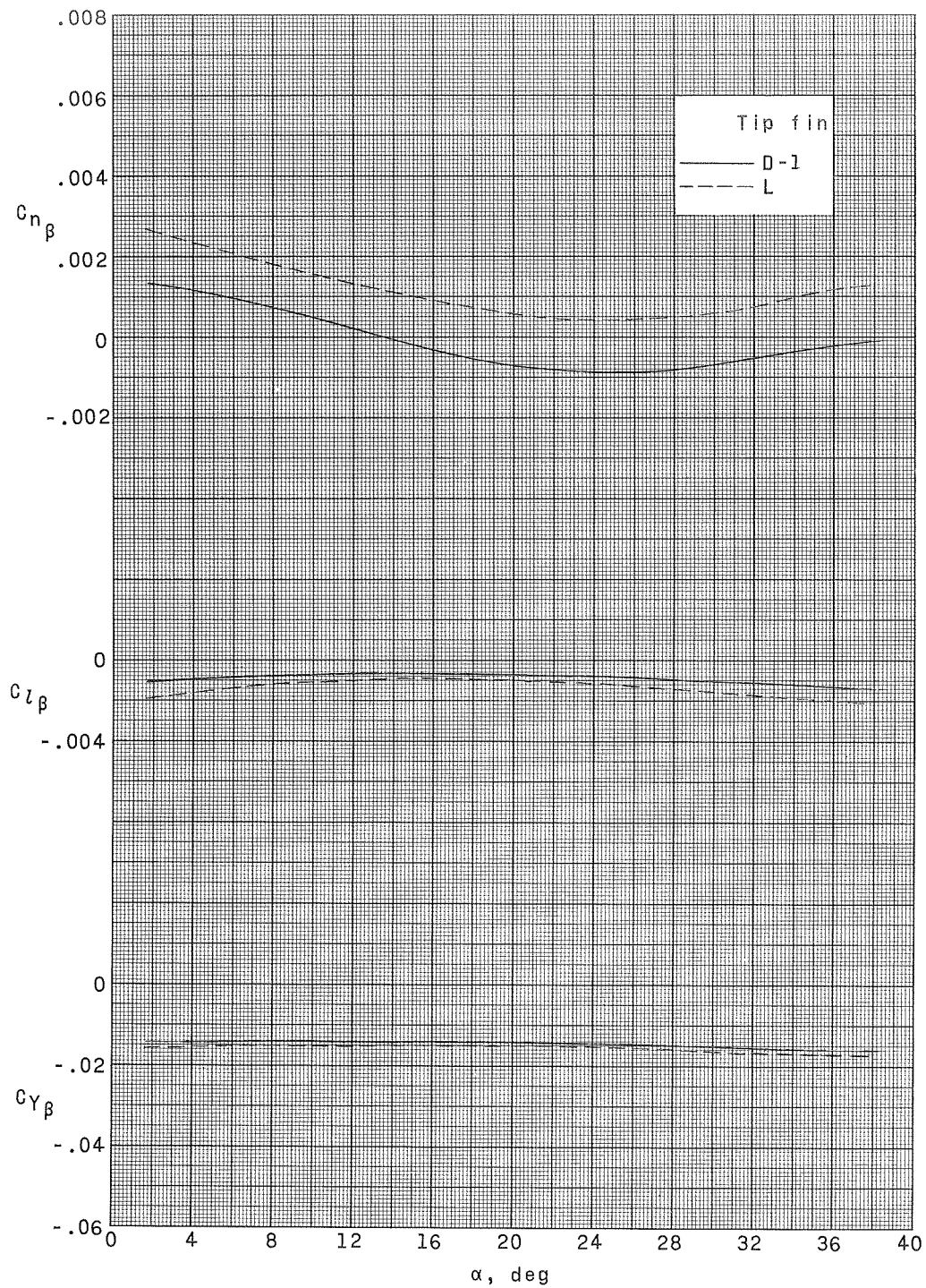
(c) M = 2.16.

Figure 9.- Continued.
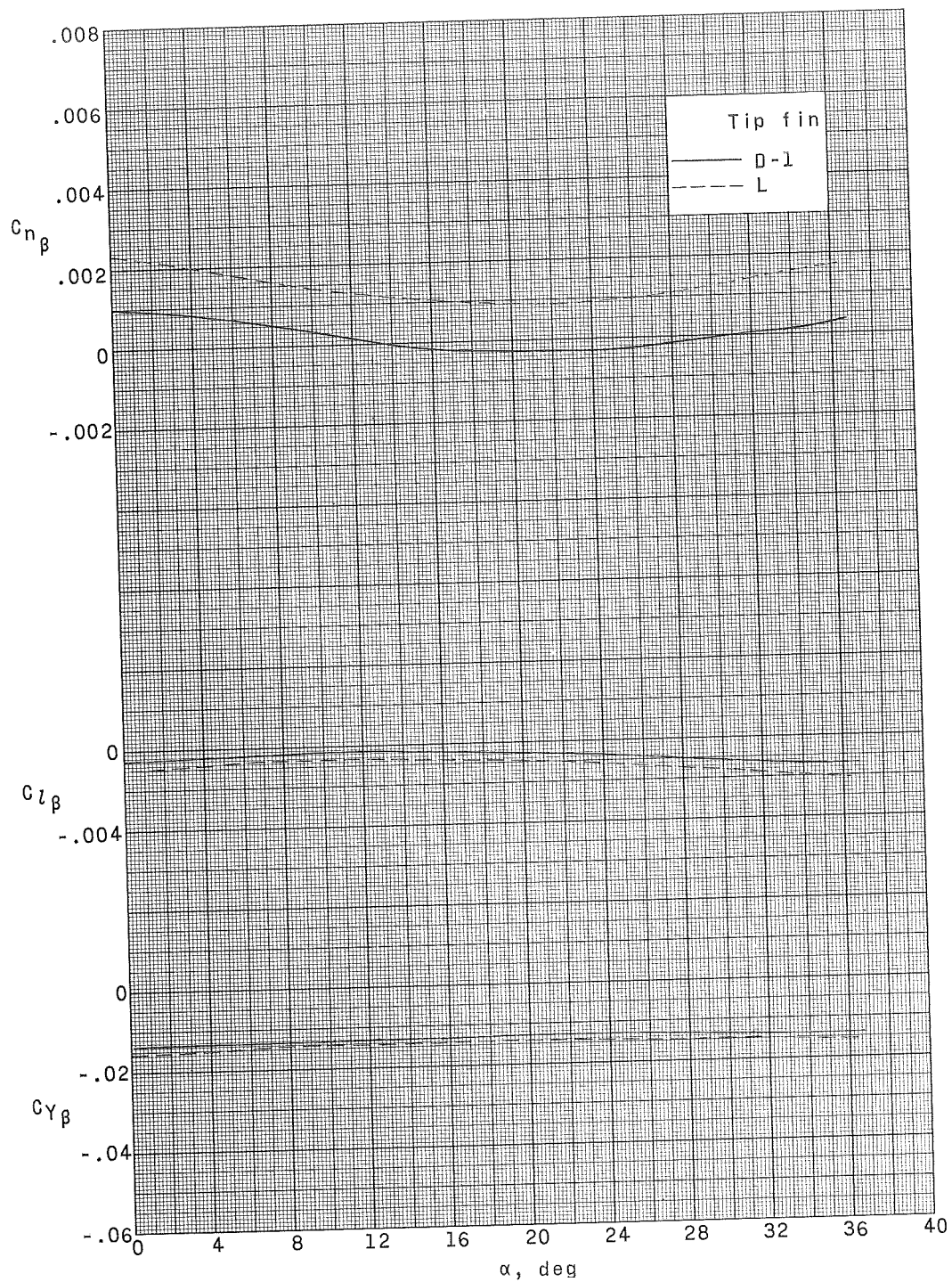
(d) M = 2.86.

Figure 9.- Concluded.
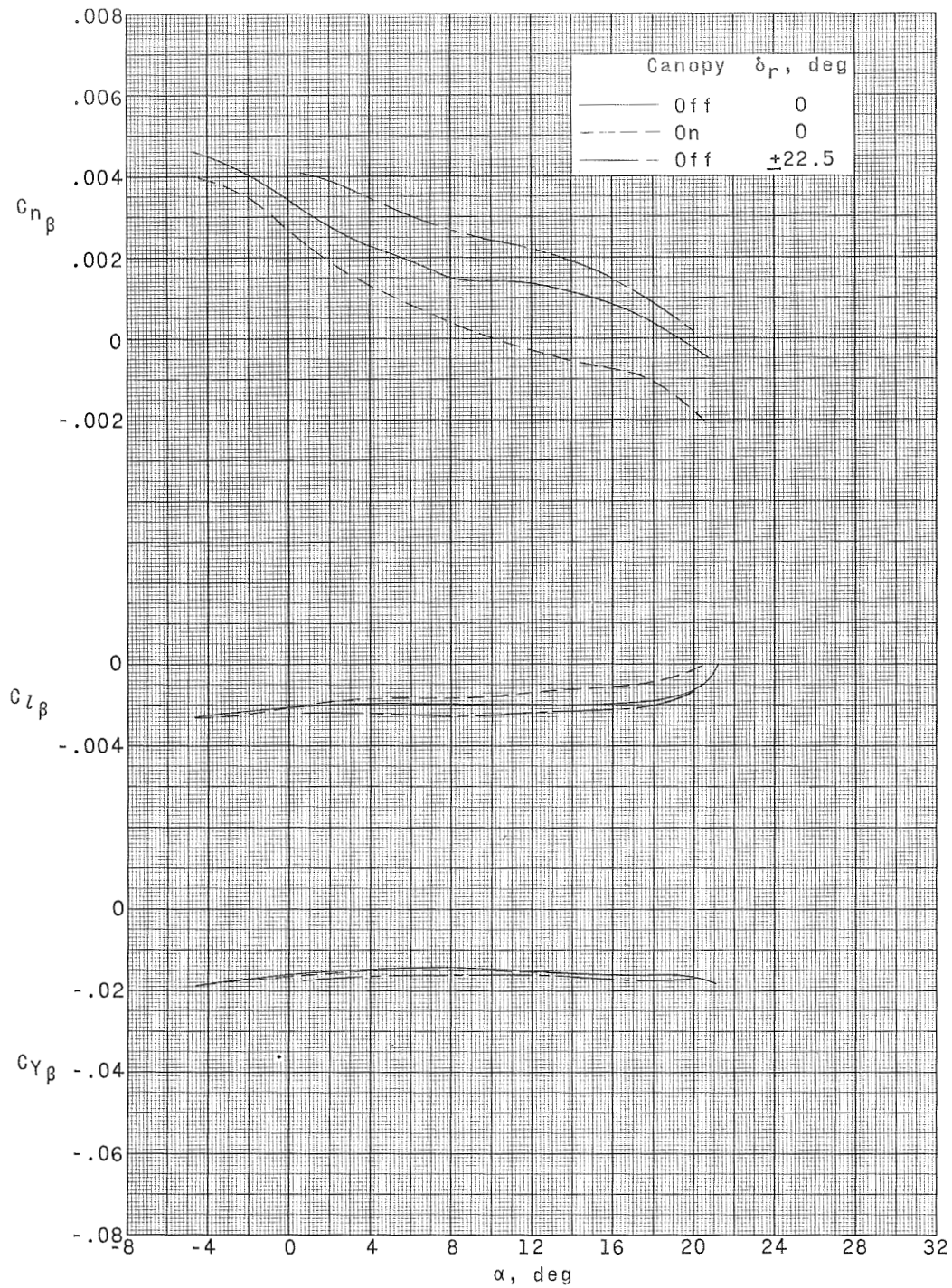
(a) M = 1.50.

Figure 10.- Lateral stability characteristics of model showing the effect of canopy and opposite deflection of rudder panels.   Tip fin J; center fin E.
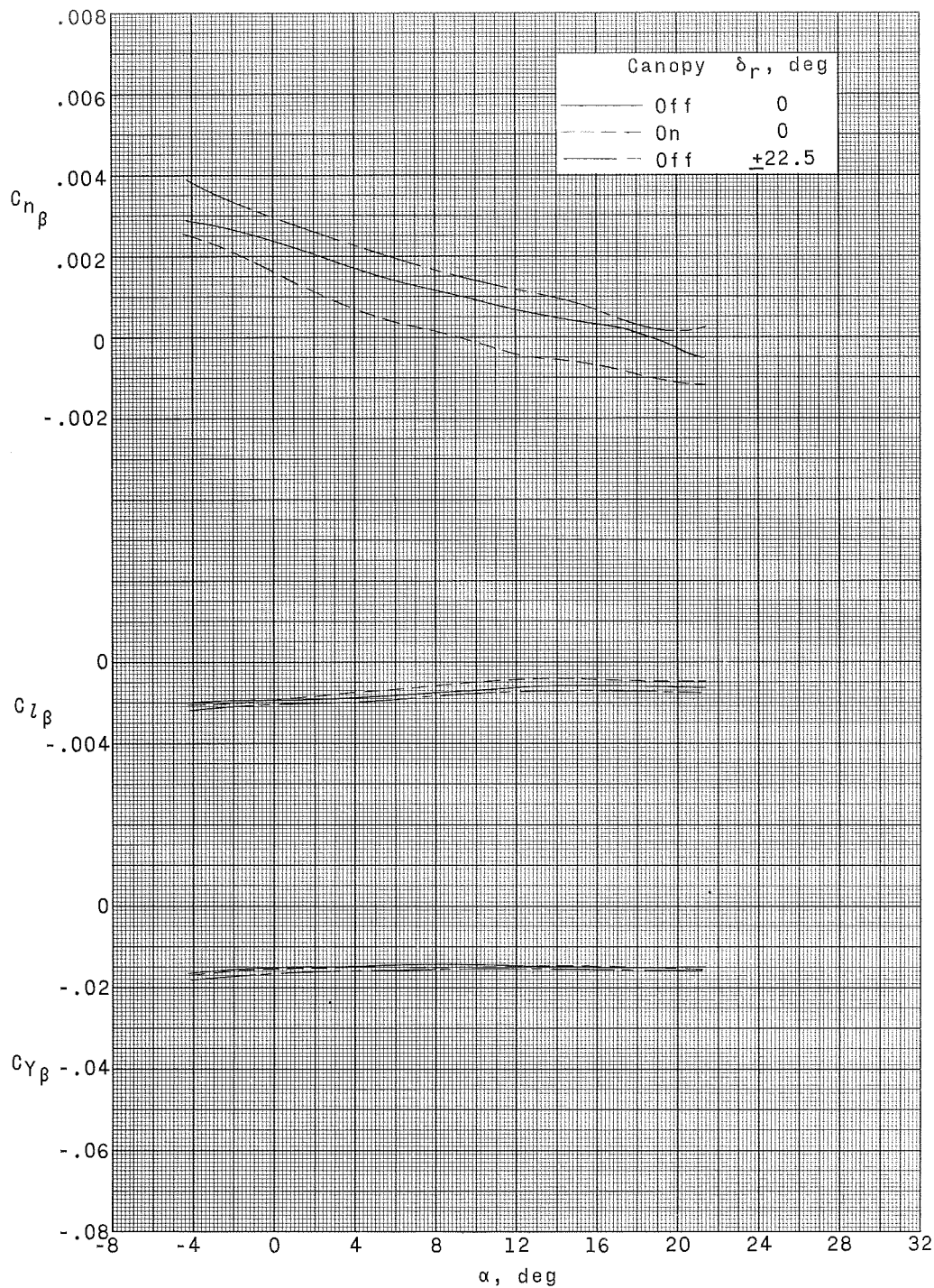
(b) M = 1.80.

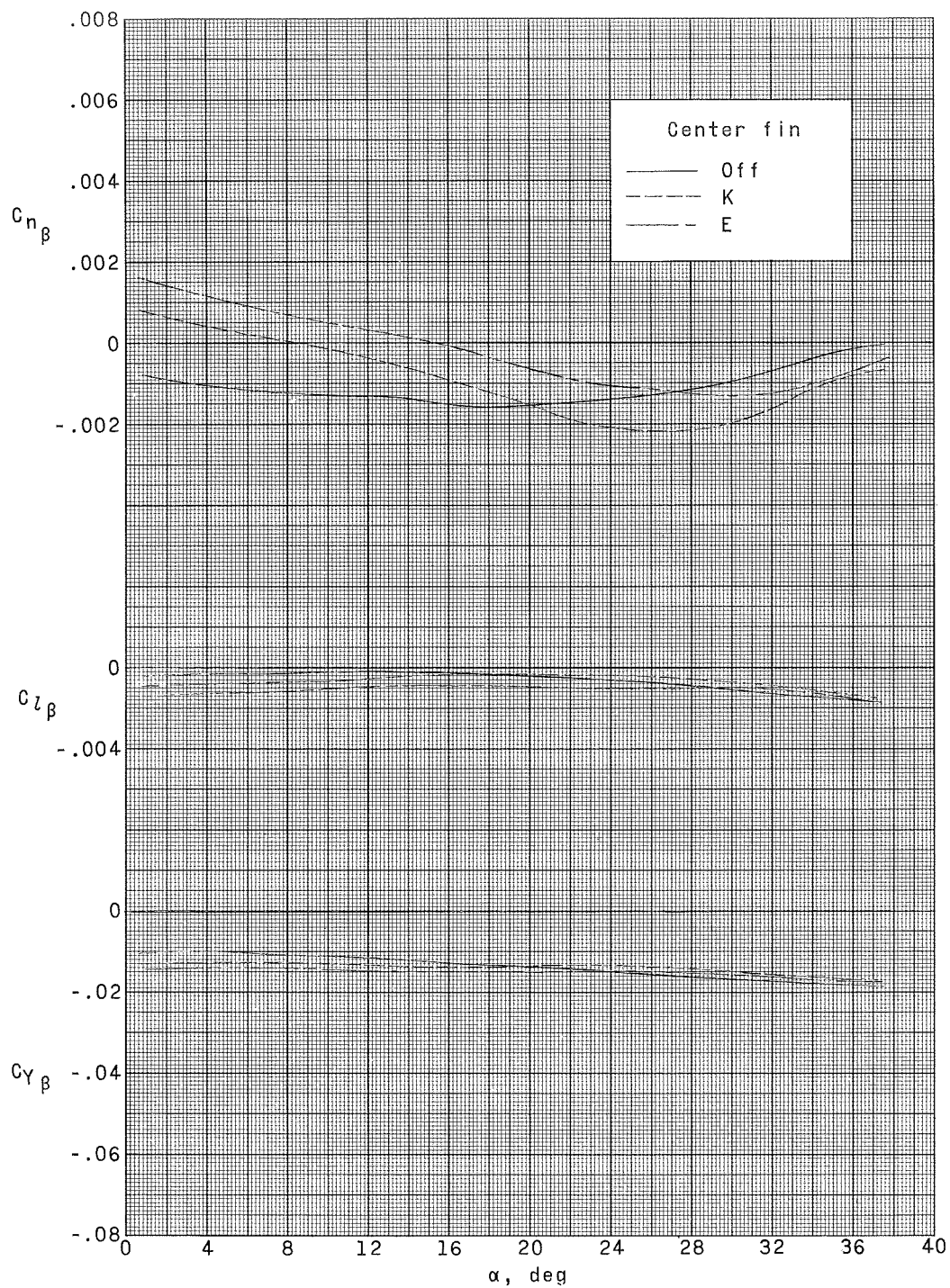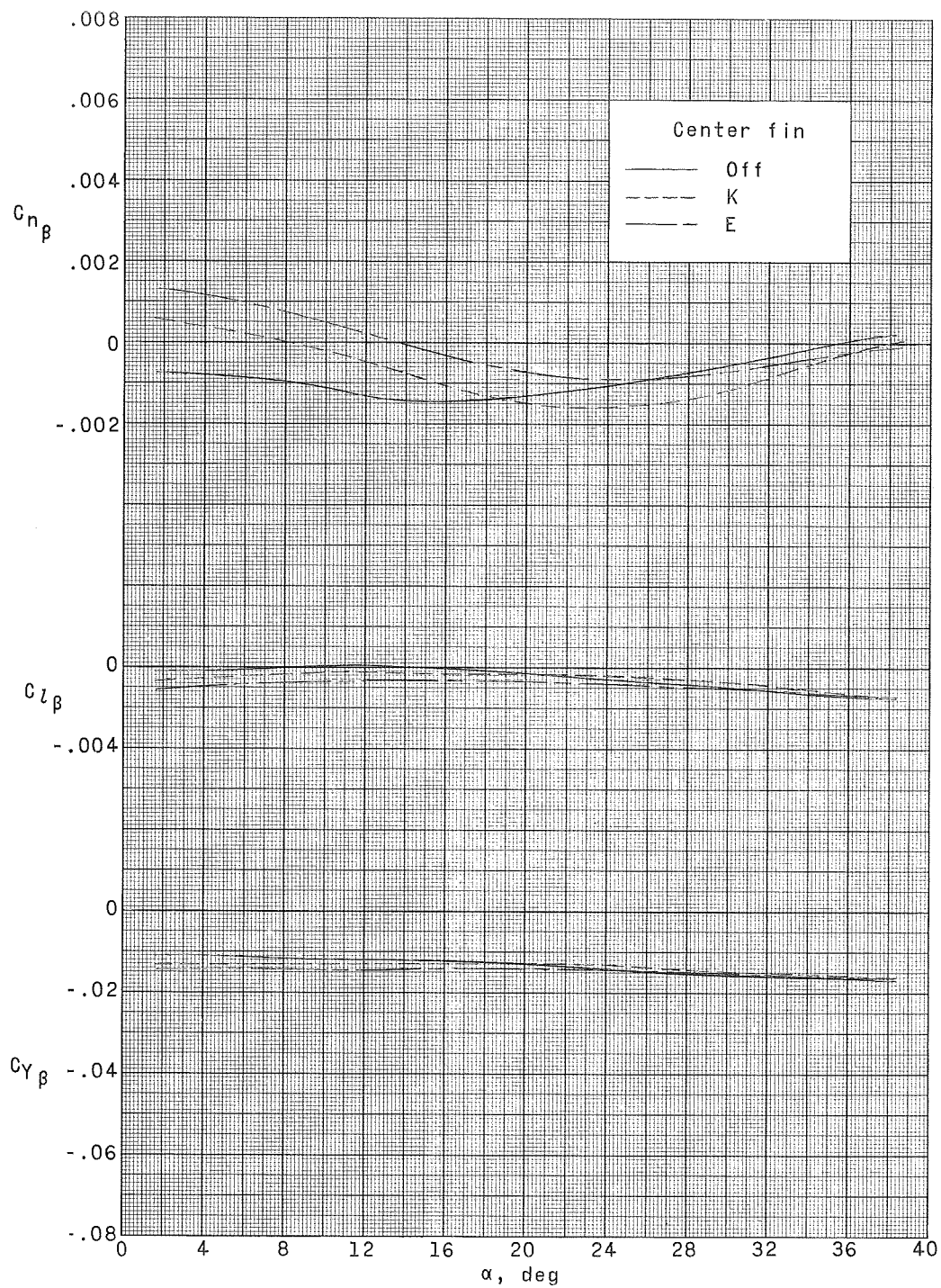Figure 10.- Continued.
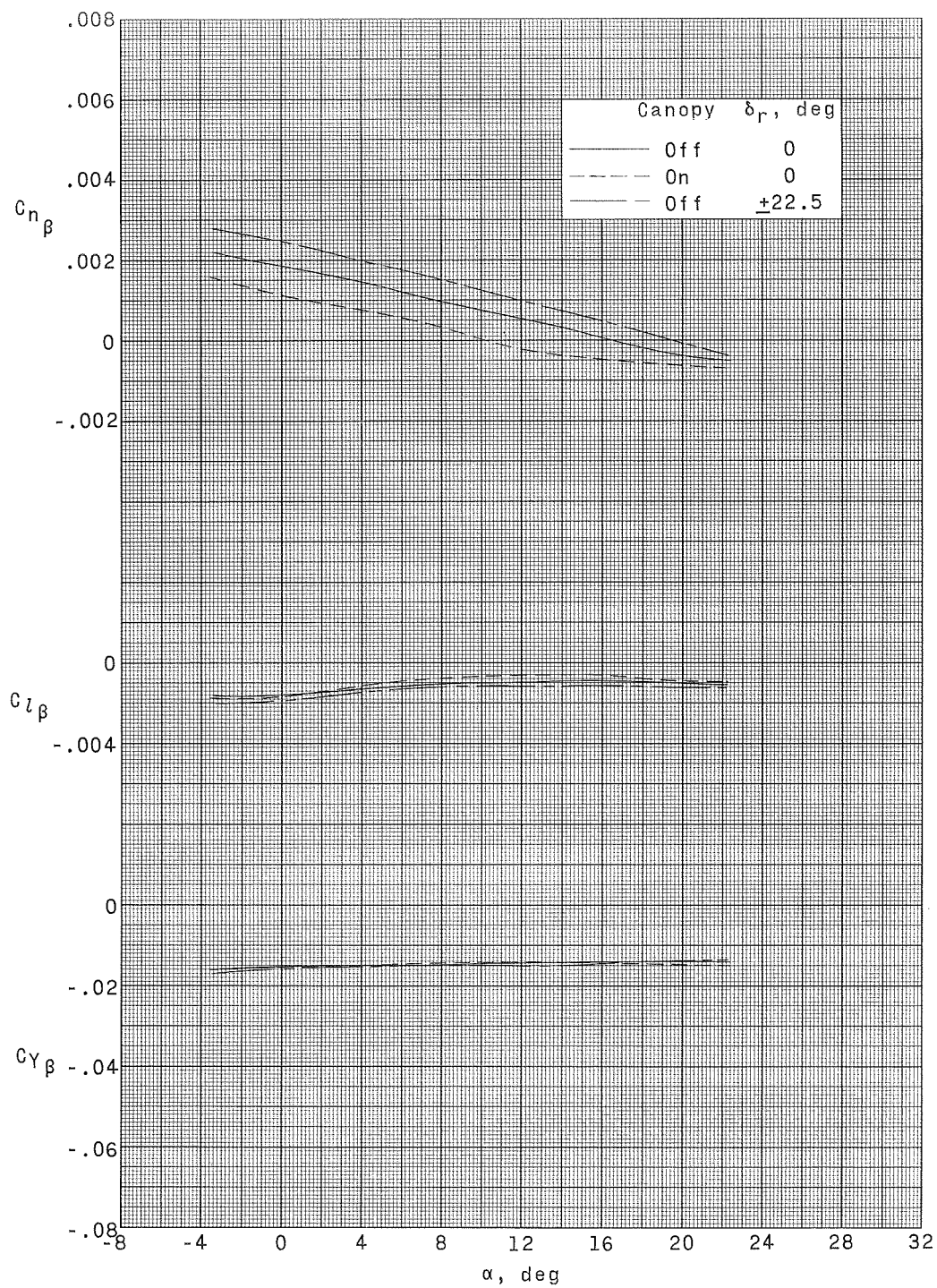
(c) M = 2.16.

Figure 10.- Concluded.
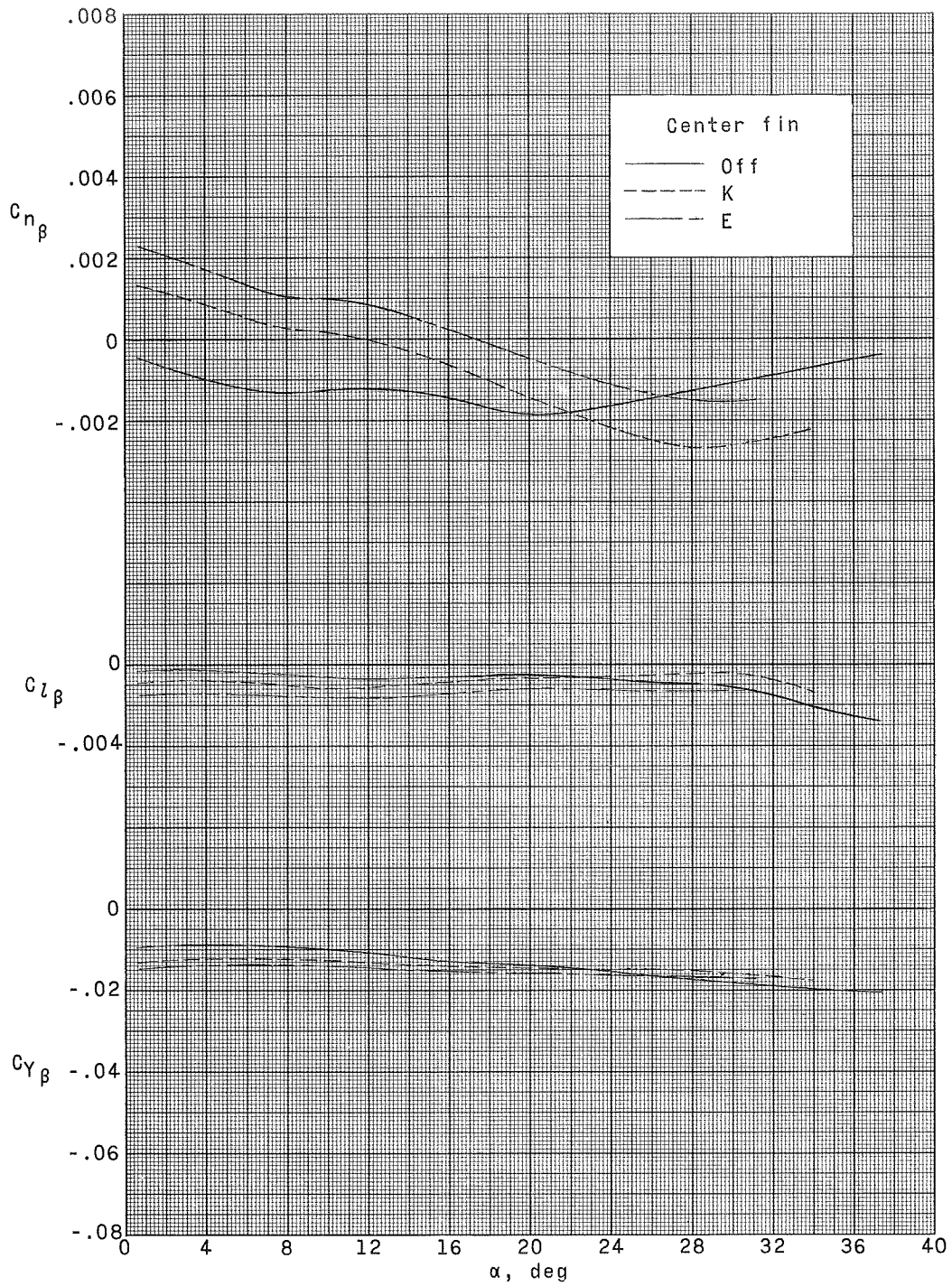
(a) M = 1.50.

Figure 11.- Lateral stability characteristics of model with various center fins. Tip fin D-1.

(b) M = 1.80.
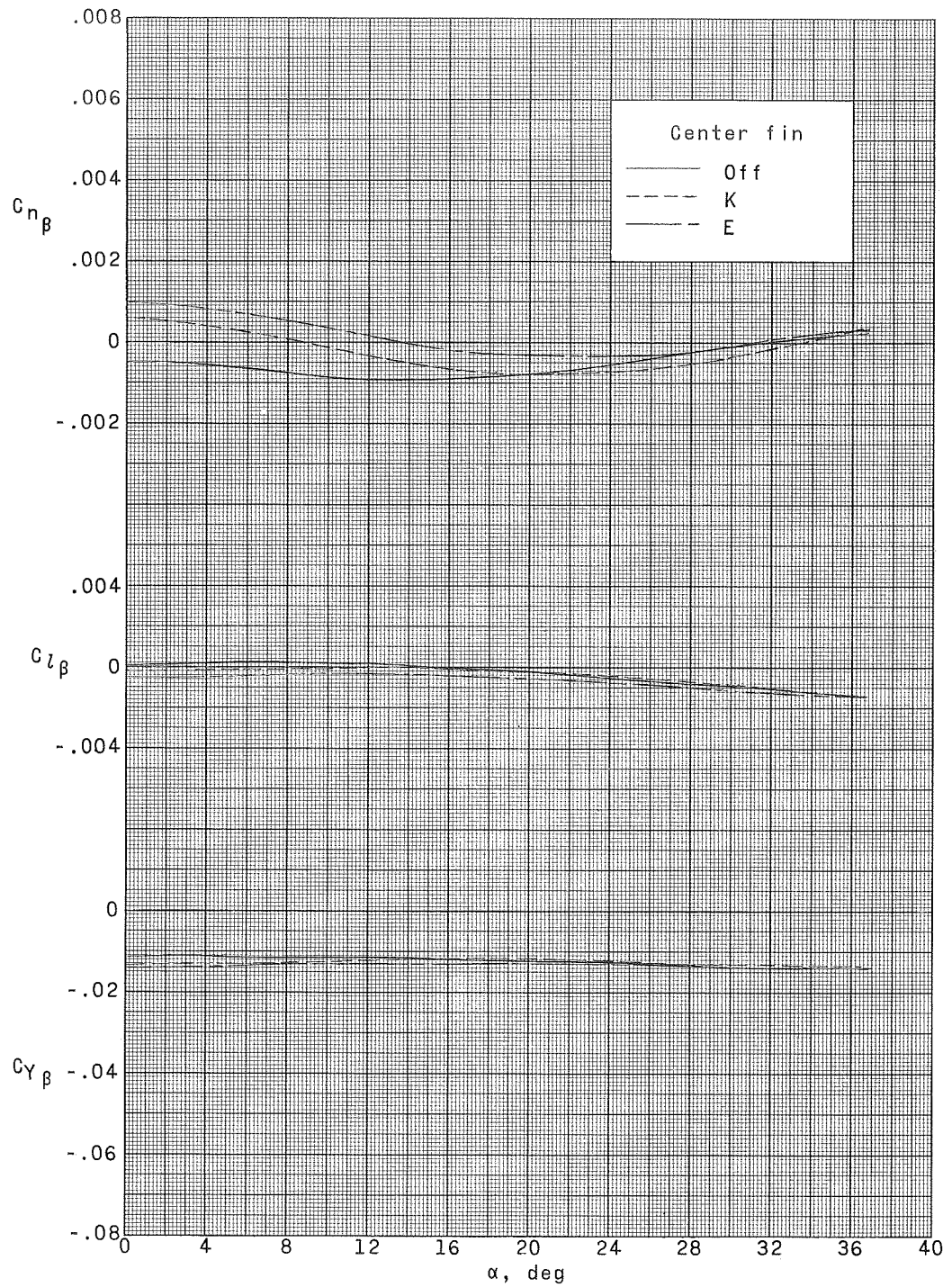
Figure 11.- Continued.

(c) M = 2.16.
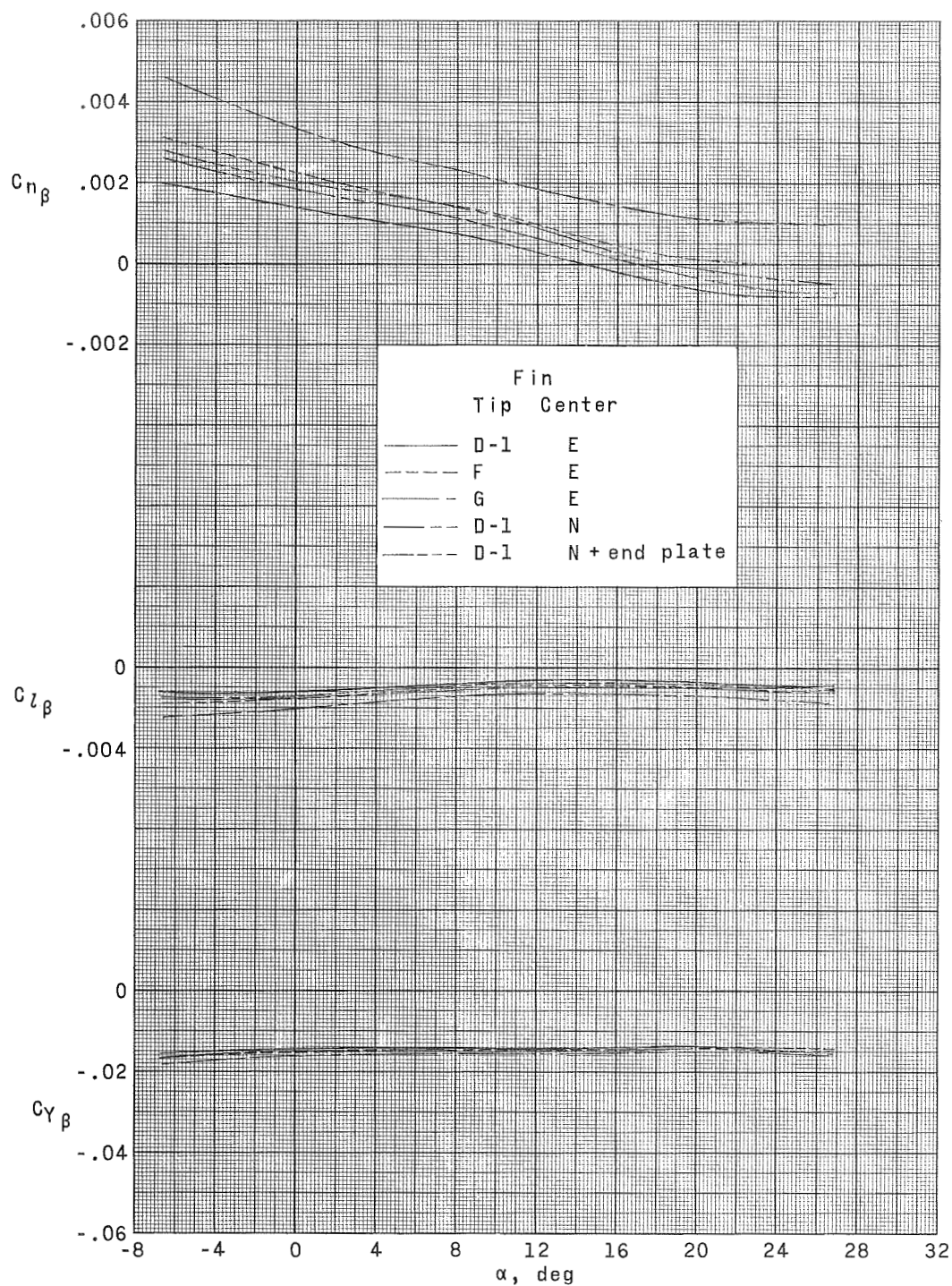
Figure 11.- Continued.

(d) M = 2.86.

Figure 11.- Concluded.

Figure 12.- Lateral stability characteristics of model with extended-chord tip and center fins, and end plate on center fin. M = 2.21.

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